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1975 AT THE NORTHEASTERN FOREST EXPERIMENT STATION

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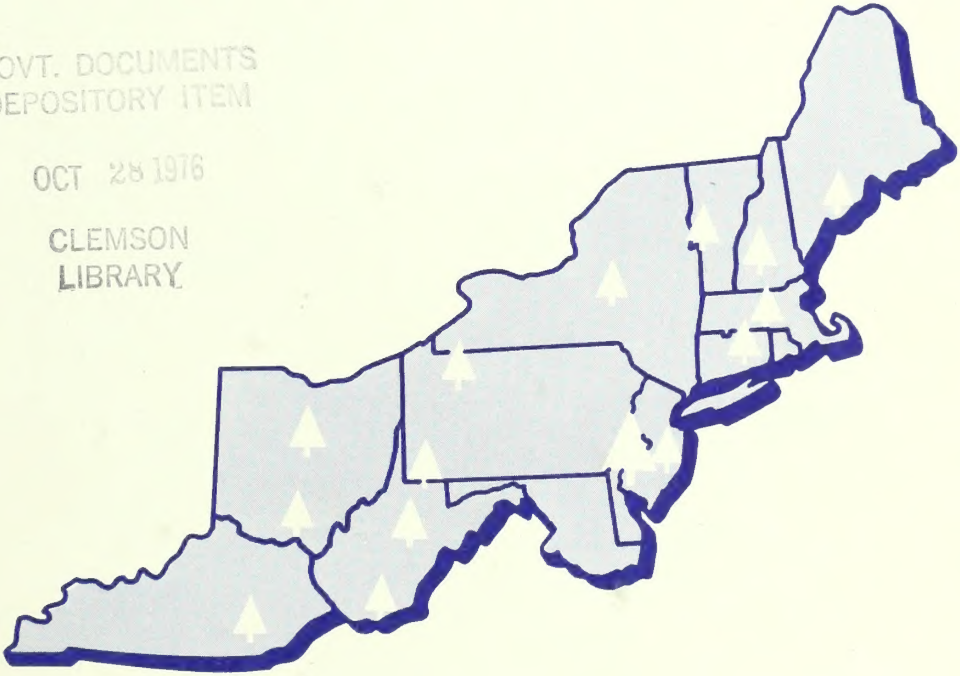

USDA FOREST SERVICE GENERAL TECHNICAL REPORT NE-24
1976

FOREST SERVICE, U.S. DEPARTMENT OF AGRICULTURE
NORTHEASTERN FOREST EXPERIMENT STATION
6816 MARKET STREET, UPPER DARBY, PA. 19082

FOREST SERVICE, U.S. DEPARTMENT OF AGRICULTURE, UPPER DARBY, PA.

1975 AT THE NORTHEASTERN STATION

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NORTHEASTERN FOREST EXPERIMENT STATION
F. BRYAN CLARK, STATION DIRECTOR ● 1976

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1975:
GENERAL

RENEWABLE FOREST RESOURCES contribute to our lives in a variety of ways. They provide wood for myriad products; they provide water, wildlife, recreation, and scenic beauty; they provide many amenities that make living more pleasant. The challenge for us is to manage our forest lands as an all-purpose renewable resource that will bring the greatest good to the greatest number, now and in the future.

For forest-resource managers, the challenge demands a mix of professional training, practical knowledge, hard work, and creative ideas. For developing the new scientific information needed to meet the challenge, a vital role has been assigned to research.

Space does not permit a review of all our research projects, so we have selected a few activities and accomplishments to highlight our diverse research program. You will also find in this report a list of the research results published in 1975.

We have recently expanded our research program in two areas. At our laboratory at Orono, Maine, research in silviculture of northern conifers—with emphasis on spruce-fir—has been expanded to include the spruce budworm and wildlife habitat considerations. We hope this combined thrust will help solve critical problems in management of millions of acres of important northern forests.

The second area of expansion deals with backcountry recreation such as hiking, backpacking, and ski-touring, and their impacts on forest ecosystems. The capacity of backcountry areas to support recreation is unknown. Management systems are needed for providing a variety of dispersed recreation opportunities, while maintaining a quality environment and meeting other resource needs. A research work unit at our Durham, New Hampshire, laboratory will develop and test management systems for insuring compatability between dispersed recreation and forest ecosystems.

Our continuing research on high-priority problems also reflects the multiple pressures on forest land. The Nation's energy crunch emphasizes the importance of our research at Berea, Kentucky, in which we are seeking better ways to rehabilitate areas strip-mined for coal.

Our gypsy moth research and development program, centered at Hamden, Connecticut, continues to focus on a comprehensive scientific approach to protecting our hardwood forests from damage by gypsy moth epidemics.

Logging research on the Fernow Experimental Forest in West Virginia is adapting skyline cable systems to the operating conditions in the Appalachian hardwood forests where slopes are steep and forest ownerships and operations are fairly small. Skyline systems have the potential of being environmentally acceptable, especially on steep slopes where logging operations are highly visible and chances of soil erosion and silting of streams are high.

Hardwood sawtimber stands in the Appalachians contain a surplus of low-grade material. Production of standard-grade lumber from grade-3 logs is generally unprofitable, so our researchers at Princeton, West Virginia, are investigating the potential for producing and marketing construction-grade plywood from grade-3 logs. Researchers there are also working with the economic and marketing problems in getting more use out of the materials usually left in the woods as logging residues.

One energy-related study deals with using old railroad crossties for fuel. U. S. railroads replace about 20 million ties annually, and railroads have a costly problem in disposing of old ties. Princeton laboratory studies indicate that 1 ton of crossties has the heating equivalent of 100 gallons of No. 2 oil, or ½ ton of high-grade bituminous coal, or 12,000 cubic feet of natural gas. Practical ways of using this potential energy resource are being pilot-tested.

Research on marketing maple syrup at our Burlington, Vermont, laboratory has caught nationwide attention and is being coordinated with our Canadian neighbors. Maple syrup is an important source of income to thousands of farmers and woodlot owners in the Northeast and in Canada. The Station and the International Maple Syrup Institute (IMSI) recently signed a memorandum of understanding providing for cooperation in research. IMSI is supported by both the Canadian and American industries and cooperates closely with the Canadian Government.

Watershed-management research by the Station continues to get international attention. Our Hubbard Brook Experimental Forest in New Hampshire is the location for important studies by both Forest Service scientists and several cooperating scientists. Related work is under way at our Parsons, West Virginia, laboratory. Research there has developed valuable information on nutrient cycling, water quality, and forest-management alternatives as well as water yields. Watershed scientists at Pennington, New Jersey, are researching problems of managing watersheds used for urban water supplies.

Within the Pinchot Institute for Environmental Forestry Research, the Consortium for Environment Studies—nine universities and the Station—continues to pursue an active cooperative research program. The Consortium also organized and sponsored three symposia in 1975: Planning and Management of the Metropolitan Physical Environment; Selection and Breeding of Trees for Densely Populated Urban Areas; and The Meaning of Natural Environments to Children.

RESEARCH HIGHLIGHTS

Northern Conifer Research Expanded To Include Wildlife and Spruce Budworm

Our research on the northern conifers (with emphasis on spruce-fir forests) has been expanded to include wildlife habitat and spruce budworm research. The research already under way in silviculture, nutrition, and growth and yield is being augmented with the addition to our staff of scientists trained in wildlife and insect research.

This multifunctional approach is designed to explore the interaction of the many factors in the forest ecosystem, ranging from intensive silvicultural practices to the effects of natural disturbances such as spruce budworm attacks and the effects of budworm control practices.

The wildlife research will emphasize the evaluation of habitat types as created or modified by other practices and events. The budworm research is designed to: (1) develop forest-management practices, consistent with sustained yield, that will limit buildup of budworm populations; (2) evaluate management systems to minimize budworm damage by taking advantage of new chemical and biological control techniques; and (3) develop an effective long-term reional forest- and pest-management system.

Progress in Reclaiming Strip-Mined Lands

A growing public concern for environment —in the face of national energy needs—has given new impetus to efforts to reclaim strip-mined lands. Our researchers at Berea KY found that shredded bark mulch, used with lime and nitrogen and phosphorus fertilizers, promoted a complete quick cover of both grasses and legumes on extremely acid (pH 2.2 to 3.5) mine spoils in eastern Kentucky.

Without mulch, only a sparse cover of grasses was obtained *(Vogel 1975)*.

In another study, Virginia pine seedlings inoculated with *Pisolithus tinctorius*, an ectomycorrhizal associate, showed better survival and growth on highly acid spoils than uninoculated seedlings did. And a photographic method—employing a background micro topographic profile gage—was developed for measuring the progress of erosion on spoil banks *(Allen and Curtis 1975)*.

Gypsy Moth Egg-Mass Sampling

In our gypsy moth program, reliable estimates of egg-mass density help in identifying potential hazard areas. We are now field-testing a point-sampling system like those used in forest inventory. Preliminary trials show that such a system not only provides reliable egg-mass density estimates at reasonable cost, but also is well suited to proiding other important diagnostic information such as tree defoliation, species composition, and timber volume and quality. Additional work is planned to increase the cost-effectiveness of the system and to modify it for use in preliminary quick scouting of potential hazard areas.

Remote-Sensing Technique Used To Measure Gypsy Moth Defoliation

Measuring the severity of defoliation done by the gypsy moth is a key tool in our research for ways to control this pest. Several methods have been tried. Last year we used a patented photometric interpretation technique developed by Calspan Corporation of Buffalo NY.* With this technique, density measurements made from camera film can be converted mathematically into reflectance values for various ground objects (soil, water, foliage, etc.).

Using a microdensitometer, Calspan developed a defoliation measure that related reflectance measurements from color infrared photographs at a scale of 1:15,680 to ground defoliation estimates. We now feel confident that a defoliation map can be produced for any location or management unit.

Progress in Use of NPV For Gypsy Moth Control

Progress is being made on the use of the gypsy moth nucleopolyhedrosis virus (NPV) as a biological control for this insect. Persistence of the gypsy moth NPV after aerial spraying was studied. Natural virus persisted much longer than sprayed virus, indicating that the formulations lack the protective ingredients found in the naturally occurring material *(Mazzone 1975)*.

Meanwhile our package of data for the registration of gypsy moth NPV is nearly ready. Modification of the production system is the present main thrust. Although the data have not yet been completely analyzed, aerial efficacy tests conducted in Pennsylvania were very encouraging.

Marketing Construction Plywood From Low-Grade Hardwood Logs

Hardwood sawtimber stands in the Appalachians contain a surplus of low-grade material. But producing standard-grade lumber from grade-3 logs is generally unprofitable; so we have been studying the possibilities of producing and marketing construction-grade plywood made from grade-3 logs. Our initial study showed that the cost was about the same as the cost for producing southern pine plywood. However, laboratory and field tests were contradictory: though the plywood did not meet the glue-bond requirements for exterior plywood, it performed well in a variety of applications.

The research was extended to see whether plywood made from a mixture of hardwood species would meet the glue-bond tests. Six species combinations met the requirements for exterior-grade plywood, and seven other combinations met the requirements for structural C-D plywood. The most suitable combinations are red oak, hickory, and hard maple for outer plies and yellow-poplar, soft maple, and black gum for inner plies *(Craft 1975)*.

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* Mention of any commercial product is for information only and should not be considered an endorsement by the Forest Service or the Department of Agriculture.

Grading System Developed For Hardwood Veneer Logs

Most hardwood veneer mills have their own log-grading systems. These grading systems are based on anywhere from two to six grades, and this is confusing for people who sell veneer logs to several mills. Also, changes in the marketing situation usually result in changes in grading procedures rather than adjustments in prices. A need has been felt for a standard log-grading system that is related to veneer yields.

A study was made to correlate face veneer yields with external characteristics of yellow birch and sugar maple logs. From this study, a preliminary grading system was developed by which veneer logs can be sorted into three distinct grades. The results suggest that a standard log-grading system can be used to predict face veneer yields *(Rast 1975)*.

Recycling Old Crossties For a New Source of Fuel

Railroads in the United States replace about 20 million crossties every year, and they have a costly problem in disposing of the old ties. Since the old ties are cut into pieces for removal, they cannot be used for fence posts or architectural purposes; so they tend to accumulate as trash along rights-of-way, where they impede drainage and create fire and safety hazards. Researchers at our laboratory at Princeton WV are studying the possibilities of using these old crossties for industrial fuel.

Laboratory studies of crosstie weight and heat of combustion have indicated that 1 ton of ties has the heating equivalent of 100 gallons of No. 2 oil, ½ ton of high-grade bituminous coal, or 12,000 cubic feet of natural gas. Projected on a national basis, this could mean a saving of 4½ million barrels of oil, 1 million tons of coal, or 24 billion cubic feet of natural gas. A full-scale test of using old ties for fuel has been planned, including methods and costs of collection, processing, and combustion *(Church 1975)*.

Studies in Marketing of Maple Products

Two research studies in marketing of maple products were begun in 1975 at our laboratory at Burlington VT. One study was to determine consumer preferences for different grades of maple syrup. Outside the maple-producing region, distinct preferences were found among Fancy grade, grade A, and grade B. Grade B, the darkest syrup, was preferred over grade A and Fancy at a ratio of 1.52 : 1. Grade A was preferred over Fancy, the lightest syrup, at a ratio of 1.09 : 1. From the result of this study, our researchers recommended that the industry should promote the lighter grades more than the darker grades.

The other study was made to determine the effects of eight different types of containers on the quality of Fancy, grade A, and grade B syrups under normal marketing and storage conditions. Results showed that, for all containers tested, a Fancy grade syrup stored no longer than 6 months at a temperature of about 24°C will hold its quality well. However, syrups stored at temperatures higher than 30°C for more than 6 months may undergo a one-grade drop in color change, especially if the syrup was already dark for its grade.

Manipulating Types of Cells In Sugar Maple Wood

In sugar maple trees the starch, from which the sucrose of the sap is derived, is stored mainly in the vascular rays—multicellular conduits that extend horizontally through the tree. There is evidence that some sugar maple trees have more sucrose in their sap than others because they have a greater proportion of these vascular rays. Now we are finding that, by stimulating cambial activity, we can manipulate the tree silviculturally to produce a greater proportion of vascular rays. The production of this kind of wood seems to continue for several years, even after a decline in cambial activity.

Strip-Cutting Moderates Impacts On Hydrologic and Nutrient Cycles

At the Hubbard Brook Experimental Forest in New Hampshire, two contemporary forest practices—block-clearcutting and progressive strip-cutting—are being studied on small watersheds to determine how they affect water yield and the nutrient ion concentrations in the streams.

In the strip-cutting, one-third of the watershed was cut over during the first 2-year cycle (one of every three sets of 82-foot-wide adjoining strips was cut). Annual streamflow increased by an average of 32 mm—about one-tenth of the estimated increase expected if the entire watershed were clearcut. In the second 2-year cycle, when another third of the watershed was cut in strips, the annual increase was 114 mm.

Nutrient ions in the stream were also affected. In the first 4 years of strip-cutting, ion concentrations increased: nitrate 7 mg/1, calcium 0.9 mg/1, and potassium 0.3 mg/1. In contrast, block-clearcutting caused maximum increases: nitrate 23 mg/1, calcium 3 mg/1, and potassium 1 mg/1. The differences indicate that the impact of complete harvesting can be moderated by changing the time span and configuration of the cutting *(Hornbeck and others 1975)*.

How Forest Vegetation Can Moderate Noise Levels

Current studies by our researchers at Pennington NJ have shown that forest vegetation can reduce noise levels, even at the frequencies common in urban areas. These studies were designed to identify what it is about forest vegetation that absorbs sound, as a basis for recommending techniques for improving the ability of forests to reduce noise levels.

It is the forest floor that is most effective for absorbing sound. Tree boles scatter the sound, and this increases absorption of sound by the forest floor. The conditions that favor sound absorption are a moist litter layer and a friable well-structured soil—in short, what forest scientists consider good soil conditions. This suggests that well-managed forests provide maximum sound absorption as well as various esthetic benefits.

Dutch Elm Disease Research

Multilure, a synthetic pheromone that attracts the European elm bark beetle, carrier of the Dutch elm disease, was evaluated as a tool for beetle-population control at Fort Collins CO and Detroit MI. Though large numbers of beetles were captured on sticky traps (1.5 million at Fort Collins and nearly 4 million in a section of Detroit), there was no apparent reduction in Dutch elm disease in either area. Pheromone-baited traps were used again in 1975 to detect the beetle in new locations, and new state and county records for the beetle were established at a number of places in the United States and Canada.

Effectiveness of methyl 2-benzimidazole carbamate hydrochloride (MBC . HCl) pressure-injected into elms has now been evaluated for 3 years. In areas where all diseased and nearby healthy elms have been injected, elm losses have been only half of those in untreated areas. Treated diseased elms have recovered (about 60 percent of those with 10-percent symptoms and 30 percent of those with 20- to 40-percent symptoms). Preliminary results of more recent studies show that injection followed by removal of symptomatic branches results in an even higher rate of recovery.

A Guide for Regenerating Allegheny Hardwoods

Heavy browsing by deer on tree seedlings inhibits the regeneration of black cherry/maple forests on the Allegheny Plateau of Pennsylvania and New York. Only in stands where advanced seedlings are abundant before cutting is regeneration satisfactory after clearcutting.

Where advance seedlings are sparse, shelterwood cutting will usually increase the number of seedlings—if competition from grasses, ferns, beech root suckers, and strip maple is not excessive. Soil drainage and the importance of esthetic and recreation uses also affect the choice of silvicultural systems and cutting methods. A recent report offers guidelines for evaluating the regeneration potential of forest stands and for prescribing the most appropriate treatments *(Marquis and others 1975)*.

A Composite Profile of the Typical Logging Operation in the Northeast

Though the wood-using industry depends on timber harvesting for its main raw material, less is known about the timber-harvesting business than about any other segment of the wood-using industry. So in 1974 an extensive survey was made of commercial logging in the Northeastern States. From the results we were able to compose a basic profile of the combination of men, equipment, and activities that operate to cut and move timber products from the forest to the mill. Here is the profile *(Herrick 1975)*:

> A 4-man logging crew, with equipment worth $38,700, moves 10 miles to a new cutting area 100 acres in size. They remove 700 cubic feet of timber products per acre. The total yield is 68,000 cubic feet, worth $440 per thousand cubic feet. The skidding and forwarding distance between stump and loading point is generally about ¼ mile, though on some jobs it may be as much as ½ mile. The hauling distance over a temporary road from the landing to a paved road is about ¾ mile, but sometimes as much as a mile. From there, the haul to a mill or purchase point is about 29 miles, sometimes as much as 34.

Results of the survey are being subjected to further analysis in an attempt to identify the key to profitable logging operations.

Nongame Birds Are Big Business

Nongame birds have something to crow about: they're big business. Our researchers at Amherst MA found that people who enjoy nongame birds spent $500 million dollars for this activity in 1974—95 percent of it for purchases of birdseed, binoculars, cameras, etc. *(Payne and DeGraaf 1975)*. This tops the $300 million spent in the same year by waterfowl hunters.

Growth and Quality of Stump Sprouts

Stump sprouts are abundant in many young even-aged Appalachian hardwood stands. Examining sprouts of red oak, black cherry, yellow-poplar, white oak, chestnut oak, and basswood, researchers in West Virginia found that a high proportion of the young stump sprouts had good stem form and had achieved excellent height and diameter growth. Stems of sprout origin should be considered strongly as future crop trees. As a follow-up to these studies, cultural practices were applied to 8- and 12-year-old sprouts selected as crop trees *(Wendel 1975)*.

Removing Understory Does Little To Improve Upland Oaks

After heavy thinnings, a vigorous and dense understory soon develops in upland oak stands, and some foresters believe that competition from a dense understory may retard growth of the overstory trees. Several long-term studies have shown that complete elimination of understory vegetation does not seem to be a very profitable forestry practice. In most of the upland oak stands studied, treatments to remove understory did not increase growth of overstory trees enough to justify cost of treatment. And there is a possibility that understory removal may have a bad effect on wildlife habitat.

Biological Control Of Decay in Trees

Our research in pathology has demonstrated that it is possible to prevent decay in trees through biological control. A common soil fungus, *Tricoderma viride,* was inoculated into artificially inflicted wounds on 200 red maple trees in New Hampshire and Maine. When the trees were dissected after 2 years, decay was found in very few of the wounds. Yet decay was found in many of the control wounds that had not been treated. Re-isolation of the fungus from most of the treated wounds indicated that the fungus did not become established in the tree: rather, it was confined within a small column of discolored wood associated with the wound *(Pottle and Shigo 1975)*.

Managing Forests to Provide Den Trees for Gray Squirrels

One of our wildlife scientists at Morgantown WV studied four different levels of management intensity for providing den trees for gray squirrels, one of the important game species of our forests. For dens, squirrels need tree cavities in which they can find winter shelter and can rear their young. The old notion that leaving old cull trees will provide enough dens has been modified, because these old culls sooner or later lose their usefulness as den trees. In his four options for management, our wildlife scientist sees also a need to provide younger and healthier trees that can be managed and treated to provide den sites. Though designed primarily for even-aged forest stands, the two more intensive options could be applied in any forest stand where dens are needed *(Sanderson 1975)*.

Multiple-Use for Watersheds? One Way to Find an Answer

Municipal water companies are coming under increasing pressure to operate their properties for a variety of uses. They dare not add activities that will jeopardize their major objective—to provide water in predictable quantities with acceptable quality. Can they do this and still respond to the pressures for multiple-use management?

At first glance multiple-use management seems incredibly complex to a watershed manager. But these complexities fall away when multiple uses are subjected one by one to a systematic evaluation and recommendation. In one research project we have adapted and expanded a general check system to develop a five-step approach that watershed managers can apply to their local needs and circumstances in the all-important preplanning stage. It is hoped that they will find this approach a useful guide, helping them to meet the water needs of their communities as well as the desires of the various groups that like to use watersheds for a variety of purposes.

A New Guide for Uneven-Age Mangaement of Northern Hardwoods

Most earlier work on uneven-age management of northern hardwood forests in New England dealt with silvicultural aspects rather than the entire managerial job. Now we have a new guide that updates the old concepts and broadens the management base to better meet current needs. This new guide gives detailed recommendations on choice of cutting method, control and prediction of yields, and removal of products.

The emphasis is on encouraging good regeneration through use of single-tree, group, and patch selection. Wide options are suggested for residual diameter distribution, depending on initial stand conditions and cutting policies. And guidelines are offered on removal and transportation of products—truck roads, skid roads, and harvesting precautions. The new guidelines provide for flexibility in practice of uneven-age management to meet a variety of owner objectives and situations *(Leak and Filip 1975)*.

First International Symposium On Acid Precipitation

A worldwide concern is growing about the increasing acidity of precipitation. In some parts of northern Europe, for example, streams once rich with fish and other aquatic life have become sterile. To explore this alarming global problem, the First International Symposium on Acid Precipitation and the Forest Ecosystem was held in May at Columbus OH, sponsored by the Experiment Station and the Ohio State University, Atmospheric Sciences Program.

The Symposium, which attracted a large international participation, focused on the potential magnitude of the problem, including interrelated topics such as atmospheric chemistry, transport of pollutants, and effect of acid precipitation on aquatic life, forest soils, and forest vegetation. The Symposium served to define the problem, its nature and extent, and to provide a basis for formulating research concepts and research direction.

PUBLICATIONS

in 1975 by staff members and cooperators of the Northeastern Forest Experiment Station, Forest Service, U.S. Department of Agriculture

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In 1975, Station personnel and their cooperators were credited with more than 200 publications—in scientific and trade journals, popular periodicals, Department of Agriculture publications, symposium proceedings, and Station papers, notes, resource bulletins, and general technical reports.

Publications and reprints that are available, in limited numbers, are marked with asterisks (*). If you want a publication, ask for it by author's name, date, and title. Address requests to the Northeastern Forest Experiment Station, 6816 Market Street, Upper Darby, Pa. 19082.

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*Allen, Rufus H., Jr., and Willie R. Curtis.
1975. **A photographic technique for moniing erosion on strip mined lands.** Photo. Appl. in Sci., Tech. and Med. 10(4): 29-31, illus.

To measure the amount of sediment eroded from areas disturbed by strip-mining, the authors photographed a microtopographic profile gage precisely positioned on preinstalled stakes. The resulting photographs can be run through a chart reader and the information can be transferred onto punched cards.

*Allen, Rufus, H., Jr., and William T. Plass.
1975. **Influence of fertilizer on survival of shrub lespedeza planted on acid spoils.** Tree Planters' Notes 26: 12-13 and 24.

In the amount and manner used, application of dicalcium phosphate and triple-superphosphate was detrimental to the survival of shrub lespedeza. However, nitrogen, when applied with rock phosphate, seemed to be beneficial to survival.

*Anspach, John C.
1975. **Current management practices on the Bethlehem Municipal Watersheds.** *In* Municipal Watershed Management Symposium Proceedings. USDA For. Serv. Gen. Tech. Rep. NE-13: 98-104, illus.

Bethlehem, Pennsylvania, derives its water from two watersheds located in the Pocono Mountains, 30 miles north of the City. The Wild Creek and Tunkhannock drainage areas measure 25,500 acres, of which the City owns 72 percent. Water from the forested watersheds does not require filtration and flows by gravity through a 23-mile transmission line to a service area of 90 square miles with a population of 105,000. The watersheds and the management practices used on them are described, including use of watershed lands for recreation and educational purposes.

*Araman, Philip A., and Edwin L. Lucas.
1975. **An automated rough mill for the production of interior furniture parts.** USDA For. Serv. Res. Pap. NE-335. 5 p., illus.

An automated rough mill has been designed for producing interior furniture parts. In this mill the lumber is gangsaw-ripped into full-length strips of standard width before the strips are marked for defects and automatically crosscut to desired lengths. Requiring only three workers, the mill was designed to reduce the need for human decisions that can be costly in converting lumber into parts.

*Auchmoody, L. R., and K. P. Hammack.
1975. **Foliar nutrient variation in four species of upland oaks.** USDA For. Serv. Res. Pap. NE-331. 16 p.

A study of 60-year-old red, white, chestnut, and scarlet oaks in West Virginia suggests that easier-to-reach foliage from the lower crown is well suited for nutrient sampling. Variability was evaluated from samples obtained from the terminal shoot, from each cardinal point in the upper and lower crown, and from the interior. Concentrations of K, Ca, and Mg were generally higher in the lower than in the upper crown, while N, P, Mn, and Fe concentrations were unrelated to position. Tree-to-tree variation was approximately the same for all crown positions. A standard field sampling procedure is suggested.

*Barger, Jack H., and Kenneth Helrich.
1975. **Field test with helicopter applications of Gardona against gypsy moth in Pennsylvania.** USDA For. Serv. Res. Pap. NE-314. 6 p.

Gardona was evaluated as a candidate toxicant for gypsy moth suppression in a field test. Egg-mass counts and defoliation estimates were made before and after spraying. Qualitative and quantitative spray-deposit assessments were conducted. A chemical assay of leaves, soil, and water was made to determine residues. Data suggested that Gardona failed to affect the gypsy moth.

Bauer, Curtis H.
1975. **The consultant's role in municipal watershed management.** *In* Municipal Watershed Management Symposium Proceedings. USDA For. Serv. Gen. Tech. Rep. NE-13: 135-140, illus.

The activities of consulting forestry firms include formulation of watershed-management policy and objectives, financing forestry services, management plans, maps, boundaries, timber sales, timber harvesting, logging control and supervision, watershed protection, esthetics, and public relations. Consultants can manage most forest watersheds to satisfy municipal policies and objectives.

Baumgras, John E.
1975. **How to avoid axle-weight overloads on tandem-axle log trucks.** North. Logger 24(3): 14-15, illus.

The results of a logging truck axle-weight study and recommendations for improving the distribution of load weight on tandem-axle logging trucks. Logging trucks weighed in West Virginia carried so much weight on the rear axles that payloads could not be maximized without exceeding the legal axle-weight limits. Improved weight distribution would enable loggers to increase legal payloads.

*Bay, Roger R., and J. S. Krammes.
1975. **Research needs related to management of municipal watersheds.** *In* Municipal Watershed Management Symposium Proceedings. USDA For. Serv. Gen. Tech. Rep. NE-13: 193-196.

Major research needs in municipal-watershed management now center around the quality of water supplies, particularly the interactions between human activities on municipal watershed lands and water quality. We need to know the impacts of various intensive and extensive recreational activities and pressures on a number of water-quality factors. Knowledge is also needed on the effects of urbanization, on-site reservoir use, and other human activities.

Bergey, Hans T.
1975. **Current management practices on the Providence Municipal Watershed.** *In* Municipal Watershed Management Symposium Proceedings. USDA For. Serv. Gen. Tech. Rep. NE-13: 115-123, illus.

The water supplied by the City of Providence (RI) Water Supply Board is obtained from a 92.8-square-mile watershed on the north branch of the Pawtuxet River. Management of departmental watershed and forest lands include forest culture and harvest practices; forest protection; and care of related facilities such as fire lanes, access roads, fences, turfed areas, and dams; and resolution of a myriad of associated people problems in an urbanizing environment.

Berry, Frederick H., and Winand K. Hock.
1975. **Walnut anthracnose.** U.S. Dep. Agric. Handb. 470: 92-94, illus.

Walnut anthracnose, caused by the fungus *Gnomonia leptostyla* (Fr.) Ces. & de. N. is a destructive disease of certain walnut species, particularly the eastern black walnut. Leaves, nuts, and occasionally shoots of the current season's growth are attacked by the fungus. When climatic conditions are favorable, trees are heavily defoliated. Walnut anthracnose can be controlled by periodic spraying with fungicides such as dodine (Cyprex).

*Blanchette, Robert A., and Edward M. Sharon.

1975. *Agrobacterium tumefaciens*, **a promoter of wound healing in** *Betula alleghaniensis*. Can. J. For. Res. 5: 722-730, illus.

Agrobacterium tumefaciens was evaluated as a promoter of wound healing on mechanically inflicted basal wounds on 50 greenhouse-grown and 45 field-grown yellow birch. Inoculated and uninoculated wounds were wrapped with a clear plastic. Treated wounds showed a 4-fold to 5-fold increase in wound closure after 30 days for greenhouse-grown trees and after 45 days for field-grown trees. Compartmentalization of the wounded tissue was stimulated by treatment with *A. tumefaciens*. Abundant vessel plugging and an enhanced zone of cells, which formed after wounding, served to compartmentalize the wound.

*Bones, James T., and James E. Blyth.

1975. **Pulpwood production in the Northeast and North Central States for 1974.** North. Logger 24(3): 8, 29.

Pulpwood production between 1973 and 1974 increased 11 percent in the 21-state area. An outstanding production advance of 16 percent over the previous year in the Lake States was partially offset by a production decline in the Central States. These statistics and others resulted from a complete canvass of woodpulp mills conducted annually by the Forest Service Experiment Stations in the East. The article contains 1974 pulpwood statistics by states and sources of pulpwood, and the number of mills that were operating.

*Bones, James T., and George H. Pierson.

1975. **Wood recovery during land-clearing operations in New Jersey.** J. For. 73: 360-363, illus.

During a resurvey of New Jersey's timber resources, a study was made to measure losses of wood fiber attributable to clearing of forest land. An estimated 120 million cubic feet of growing stock were destroyed on the 164,000 acres of commercial forest land cleared between 1955 and 1971. Most of the recovered industrial wood fiber came from forest lands converted to agricultural use, and most of the recovered firewood came from home-building sites.

*Bowen, David K.

1975. **Soil conservation—A parameter of quality water yields.** *In* Municipal Water shed Management Symposium Proceedings. USDA For. Serv. Gen. Tech. Rep. NE-13: 162-166.

Reviews (1) soil conservation methods used by landowners, (2) conservation objectives in small watershed projects, (3) conservation work in multicounty resource conservation and development projects, (4) the use of soil surveys as natural resource-planning aids, and (5) a newly authorized system of land inventory and monitoring.

Brasier, C. M., and J. N. Gibbs.

1975. **Variation in** *Ceratocystis ulmi*: **significance of the aggressive and nonaggressive strains.** *In* Dutch elm disease: 53-66, illus. USDA For. Serv. Northeast. For. Exp. Stn., Upper Darby, Pa.

Discovery of two strains of *C. ulmi* in Britain raised a question about the origin of the aggressive strain in the current epidemic: did it arise by genetic change within an endemic nonaggressive gene pool, or was it introduced? The aggressive strain has apparently declined in northwestern Europe, but not in North America.

*Burdekin, D. A., and H. M. Heybroek [ed.].

1975. **Dutch elm disease.** USDA For. Serv. Northeast. For. Exp. Stn., Upper Darby, Pa. 94 p.

Dutch elm disease research and control, past and present, and prospects for the future were the subjects of this interdisciplinary meeting. The proceedings contain four lead papers that deal with: (1) chemical control of the pathogen; (2) chemical and biological control of the beetle vectors; (3) aggressive and nonaggressive strains of the pathogen; and (4) sanitation as a disease control measure. Also included are discussion comments from conference participants.

Byrne, Kevin J., William E. Gore, Glenn T. Pearce, and Robert M. Silverstein.

1975. **Porapak-Q collection of airborne organic compounds serving as models for insect pheromones.** J. Chem. Ecol. 1(1): 1-7.

Organic compounds with properties resembling those of insect pheromones can be removed from an airstream by absorption on Porapak-Q and recovered from the absorbent by extraction. When this procedure is applied to aeration of live insects, the Porapak extract represents a concentration of the chemical.

*Campbell, Robert W.

1975. **The gypsy moth and its natural enemies.** U.S. Dep. Agric. Inf. Bull. 381. 27 p., illus.

Patterns of gypsy moth behavior are described, especially those related to population density. Natural mortality-causing factors that operate against this insect are also described. Several agents kill subadult male and female gypsy moths at different rates. Major determinants of year-to-year changes in gypsy moth numbers are described.

*Campbell, Robert W.

1975. **The bimodality of gypsy moth,** ***Porthetria dispar*** **(L.) (Lepidoptera: Lymantriidae) populations.** J. N.Y. Entomol. Soc. 83(4): 287-288.

Populations of the gypsy moth in North America have two numerical phases. A population may remain in an innocuous phase for many years, yet an outbreak phase may develop and continue for as much as a decade. A procedure was developed to determine at what point during the generation the numerical differences appear between a sparse population in an outbreak area and one in an innocuous area.

*Campbell, Robert W., David L. Hubbard, and Ronald J. Sloan.

1975a. **Patterns of gypsy moth occurrence within a sparse and numerically stable population. Environ.** Entomol. 4: 535-542, illus.

Patterns of subadult gypsy moth occurrence within a sparse, numerically stable population that was studied in 1965 were modelled as functions of insect stage and components of environmental structure. Results imply that: (1) Once newly hatched larvae find suitable foliage, they tend to stay on or near it until after they have molted into instar III. (2) These insects begin to wander sometime before reaching instar IV, and continue to do so until suitable daytime resting locations are found. (3) Most of the insects pupate in the locations used earlier for resting sites. (4) Bark flaps may have provided less hazardous resting sites for the growing larvae and pupae than other potential resting sites.

*Campbell, Robert W., David L. Hubbard, and Ronald J. Sloan.

1975b. **Location of gypsy moth pupae and subsequent pupal survival in sparse, stable populations.** Environ. Entomol. 4: 597-600.

About 90 percent of the gypsy moth pupae found in a series of sparse stable populations studied between 1965 and 1968 were either beneath bark flaps or in the litter. Male larvae were more likely to pupate in bark flaps than females. Pupal survival was usually higher among pupae beneath bark flaps than among those in the litter, and bark flaps provided virtually the only pupation locations in the whole environment, within the highest density stratum studies, where female pupae had a reasonable survival probability. Adult gypsy moth production in these populations could be accurately estimated from knowledge of pupal density and sex ratio and the number of bark flaps per 0.01 acre. Bark flap removal is suggested as a potentially useful technique for preventing outbreaks.

*Church, Thomas W., Jr.

1975. **Steam up with old crossties? Maybe!** South. Lumberman 231 (2872): 78, illus.

Disposal of old crossties costs the Nation's railroads millions of dollars each year. Studies of crosstie weights and heat outputs revealed that the old ties might be a valuable source of industrial fuel. Nationwide, the production of steam from discarded ties could replace the consumption of 4½ million barrels of fuel oil. A preliminary cost analysis indicates that this practice could be profitable.

Clark, F. Bryan.

1975. **La plantation du noyer noir a bois.** Bull. de la vulg. for. 75/2: 50-51.

A translation into French of USDA Forest Service Leaflet 487, "Planting black walnut for timber" (1971 revision). The leaflet contains advice on selecting the right site, preparing the planting area, planting seedlings or seed, providing adequate growing space, and tending the trees. Also notes on where to obtain professional advice.

*Corbett, Edward S., and John M. Heilman.

1975. **Effects of management practices on water quality and quantity: The Newark, New Jersey, municipal watersheds.** *In* Municipal Watershed Management Symposium Proceedings. USDA For. Serv. Gen. Tech. Rep. NE-13: 47-57, illus.

The 36,000-acre Pequannock Watershed owned by the City of Newark provides about one-half of the water supply of Newark and adjacent cities. The collection and delivery of high-quality water to the city is the primary management objective. A cooperative study of effects of chemical control of vegetation on water quality and yield is described.

Corbett, Edward S., James A. Lynch, and William E. Sopper.

1975. **Forest-management practices as related to nutrient leaching and water quality.** Non-Point Sources Water Pollut. Conf. Proc.: 157-173. Va. Polytech. Inst. and State Univ. Va. Water Resour. Res. Cent., Blacksburg.

The effects of forest-management practices on water quality in the eastern United States are reviewed. Changes in stream nutrient concentrations, water temperature, turbidity, and sedimentation are quantified. Stream nutrient and temperature gradients from the headwaters to the mouth of both forested and clearcut watersheds are evaluated.

Corbett, E. S., W. E. Sopper, and J. A. Lynch.

1975. **Watershed response to partial area applications of simulated rainfall.** Proc. Int. Symp. Hydrol. Charact. River Basins (Tokyo). IASH-AISH Publ. 117: 63-73.

Application of simulated rainfall to a 7.9-hectare watershed showed that during the rising limb of a storm hydrograph, stormflow came first from the channel area, then from farther upslope as soil saturation extended upslope. The duration of peakflow and the rate of decline of the recession limb until quickflow ended were controlled by the upper slope. Most of the runoff was as quickflow, and different parts of the watershed contributed different proportions of it.

*Corbett, Edward S., and Warren Spencer.

1975. **Effects of management practices on water quality and quantity: Baltimore, Maryland, municipal watersheds.** *In* Municipal Watershed Management Symposium Proceedings. USDA For. Serv. Gen. Tech. Rep. NE-13: 25-31, illus.

The City of Baltimore is conducting research on the effects of vegetation management on water yield and quality. Three small watersheds, ranging in size from 22 to 38 acres, have been selected. Converting open land to a pine forest caused a substantial reduction in water yield. The effects of removing riparian-zone vegetation and thinning young pine plantations are evaluated.

*Craft, E. Paul.

1975. **Construction grade hardwood plywood industry: an Appalachian opportunity.** Plywood & Panel 16(5): 26-28, illus.

Because of the large volume of surplus low-grade hardwoods in the Appalachians, the feasibility of producing construction-grade plywood from low-grade timber was investigated. Veneer from 10 species of Appalachian hardwoods was made into 44 different species combinations of plywood test panels, bonded with a standard pine-type phenolic adhesive mix. Twenty specimens from each panel were tested for glue-line quality, and 16 of them met the PS 1-66 standards for structural C-D plywood; 12 of these panels also met the requirements for exterior plywood.

*Cuppett, Donald G., and E. Paul Craft.

1975. **Low-temperature forced air drying of Appalachian hardwoods.** USDA For. Serv. Res. Pap. NE-328. 10 p., illus.

A guide for commercial application of low-temperature forced-air drying of Appalachian hardwood lumber, providing (1) descriptions of dryer design and construction, (2) drying schedules and estimated drying times for different thicknesses of commercially important species, and (3) detailed instructions for dryer operation.

*Cuthbert, R. A., W. N. Cannon, Jr., and J. W. Peacock.
1975. **Relative importance of root grafts and bark beetles to the spread of Dutch elm disease.** USDA For. Serv. Res. Note NE-206. 4 p.

Root-graft transmission of Dutch elm disease is sometimes ignored in both research studies and control programs. Our results indicate that elms adjacent to 1-, 2-, or 3-year-old stumps have a disease rate three to five times higher than elms not adjacent to stumps. We conclude that in Detroit, which has elm plantings typical of many United States cities, root grafts were probably responsible for more than 50 percent of the disease transmission in 1973.

*Cuthbert, Roy A., and John W. Peacock.
1975. **Attraction of *Scolytus multistriatus* to Pheromone-baited traps at different heights.** Environ. Entomol. 4: 889-890.

Trap height has an important effect on the number of *Scolytus multistriatus* captured at pheromone-baited traps. Stikem-coated traps, baited with synthetic pheromone, were placed at heights of 3, 7, and 12 meters on healthy elms during the 1st beetle flight period and on both healthy and diseased elms during the 2nd flight period. Traps at 3 m were clearly the most effective in catching beetles on both healthy and diseased trees during both flight periods.

Czapowskyj, Miroslaw M.
1975. **Book review of Forstliche Pflanzenernaehrung und Duengung,** by Hans J. Fiedler, Wolfgang Nebe, and Friedrick Hoffman; Fischer Verlag, Jena. Soil Sci. 120: 314.

This book is a scholarly treatise on forest nutrition, fertilization, and melioration, with emphasis on research findings in Germany and Central Europe where intensive silviculture is practised. (In German.)

*Dale, Martin E.
1975. **Effect of understory removal on growth of upland oak.** USDA For. Serv. Res. Pap. NE-321. 10 p., illus.

The amount of additional growth attributed to complete eradication of all woody understory vegetation varied for several widely scattered upland oak stands. Based on paired-plot comparisons of 10 or more years' results, basal-area and cubic-volume growth usually increased slightly when the understory was eradicated. The amount of increase was related to (1) geographical stand location, (2) stand age, and (3) residual stocking of overstory trees. The greatest response to understory removal was found in very young stands located in the western part of the oak range where residual density of stocking after thinning was about 50 percent. For most upland oak stands, understory removal would not greatly increase stand growth.

*Darrach, Alfred.
1975. **State technical assistance programs.** *In* Municipal Watershed Management Symposium Proceedings. USDA For. Serv. Gen. Tech. Rep. NE-13: 181-184.

Each of the 12 Northeastern States provides some technical assistance for municipal-watershed management. The state forester supplies technical help on forested land. Other state agencies concentrate on public health, fish and wildlife, ground water, and law enforcement. Few state foresters feel that an intensive municipal watershed program is needed.

Davidson, Walter H.
1975. **Amendments aid reclamation plantings on bituminous mine spoils in Pennsylvania.** Pa. For. 65: 101-104.

Treatments of lime, fertilizer, and hardwood bark mulch were applied to four spoil areas in the Bituminous Region of Pennsylvania. The plots were planted to red pine and seeded to a mixture of weeping lovegrass, K-31 tall fescue, and Korean lespedeza. Pine survival did not benefit from the amendments. Establishment of weeping lovegrass and K-31 tall fescue was better on amended subplots than on control subplots. Korean lespedeza did poorly on all subplots.

Demeritt, M. E., Jr., H. D. Gerhold, and E. H. Palpant.
1975. **Genetic evaluation of two-year height of Scotch pine seedlings.** Northeast. For. Tree Improve. Conf. Proc. 22: 148-158.

Genetic analyses of 2-year height of full- and half-sib Scotch pine seedlings (*Pinus sylvestris* L.) from inter- and intraracial matings were performed to estimate heritability, within-plot variance, and to see if nursery selection would be effective. Interpopulation heritability estimates were greater than intrapopulation matings, probably due to differences in gene frequencies between populations used. In general, with greater diversity in germplasm there was larger variation within plots. Estimates of heritability indicated that mass selection for early height growth would be effective under the conditions of this experiment.

Demeritt, M. E., Jr., and H. W. Hocker, Jr.
1975. **Influence of seed weight on early development of eastern white pine.** Northeast. For. Tree Improve. Conf. Proc. 22: 130-137.

Three eastern white pine seed sources were grown for 2 years in the field as a result of direct-seeding and in pots in a greenhouse to see what effect seed weight has on seedling development. Seed weight among sources influenced the size of 2-year-old direct-seeded seedlings, but not greenhouse-grown seedlings. Seed weight within sources influenced the size of 2-year-old greenhouse grown seedlings.

Dissmeyer, George E., E. S. Corbett, and W. T. Swank.
1975. **Summary of municipal watershed management surveys in the eastern United States.** *In* Municipal Watershed Management Symposium Proceedings. USDA For. Serv. Gen. Tech. Rep. NE-13: 185-192, illus.

The U.S. Forest Service conducted two municipal-watershed-management surveys in the eastern United States, using mailed questionnaires to (1) determine the importance of surface-water supplies, (2) inventory the land uses allowed in these watersheds, (3) inventory the nature and extent of various land-management problems related to water supplies, and (4) determine what information and management practices are needed to improve watershed management and water supplies.

Dochinger, Leon S.
1975. **Improving city air quality with trees.** *In* Forestry issues in urban America. Soc. Am. For. Proc. 1974: 113-120.

In addition to esthetic and climatic amenities of greenbelts in urban communities, trees may condition contaminated air and reduce daily pollution levels. Planning approaches toward minimizing toxic concentrations in urban areas are considered. Research priority must be given to delineating inherent potentials of trees for cleansing urban environments. Then realistic interpretations and subsequent greenspace implementation can be developed, which in turn will facilitate the filtration and dispersion of aerial toxicants by trees in urban America.

*Dochinger, Leon S., and Keith F. Jensen.
1975. **Effects of chronic and acute exposure to sulphur dioxide on the growth of hybrid poplar cuttings.** Environ. Pollut. 9: 219-229, illus.

Hybrid poplar clones were fumigated in controlled-environment chambers with either 5 ppm sulphur dioxide for 1½, 3, and 6 hours or with 0.25 ppm sulphur dioxide for 6 weeks. Multivariate analyses were made from shoot-growth data before and after treatment and on the foliar injury induced by SO_2. Both short- and long-term fumigation produced similar plant-behavior responses to the two SO_2 concentrations.

Dochinger, Leon S., and Thomas A. Seliga.
1975. **Acid precipitation and the forest ecosystem.** J. Air Pollut. Control Assoc. 25: 1103-1105.

Acid precipitation is of increasing concern among international scientists because of its potential long-term injurious effects on the growth and production of agricultural crops. In conjunction with The Ohio State University, the Experiment Station cosponsored the First International Symposium on Acid Precipitation and the Forest Ecosystem. The findings will establish the state of knowledge of the acidity phenomenon and help to determine research priorities.

*Douglass, James E., and Wayne T. Swank.
1975. **Effects of management practices on water quality and quantity: Coweeta Hydrologic Laboratory, North Carolina.** *In* Municipal Watershed Management Symposium Proceedings. USDA For. Serv. Gen. Tech. Rep. NE-13: 1-13, illus.

Results from nearly 40 years of watershed experiments at Coweeta are summarized. An equation is presented for predicting the annual increase in streamflow from the percent basal-area cut and from the theoretical extraterrestial radiation load for the watershed. Timing of the increased flow from watershed experiments depends on the magnitude of the increase, but results consistently show that much of the increase appears in the low-flow season.

Echelberger, Herbert E., George H. Moeller, and Raymond E. Leonard.
1975. **Recreation problems and opportunities.** *In* Municipal Watershed Management Symposium Proceedings. USDA For. Serv. Gen. Tech. Rep. NE-13: 154-161, illus.

Demand for water-oriented outdoor recreation continues to increase, especially near urban areas. As these demands rise, municipal watershed managers can expect to feel increased pressure for recreational use of land and water resources under their jurisdiction. The authors discuss some of the problems associated with recreational use of municipal watersheds and present some ideas for managers who anticipate recreational use pressures.

*Eschner, Arthur R., and Donald L. Mader.
1975. **Management implications of other hydrologic research in the Northeast.** *In* Municipal Watershed Management Symposium Proceedings. USDA For. Serv. Gen. Tech. Rep. NE-13: 66-78, illus.

Research results from a wide array of institutions are reviewed, mostly about the effects of various activities on the amount of water and the timing of its availability; information about the impact on water quality is more limited. Interception effects caused by tree species, the characteristics and water-storage capacities of their associated humus layers, significance of sources of storm runoff, and effects of management of streamside vegetation are discussed.

*Fay, Stephen.
1975. **Ground-cover vegetation management at backcountry recreation sites.** USDA For. Serv. Res. Note NE-201. 5 p.

Increasing use of remote backcountry recreation sites in the Northeast is resulting in a loss of the thin soil mantle and destruction of the ground-cover vegetation. Fencing, fertilization, and liming and a combination of all three were tested as means of reestablishing ground-cover vegetation on bare mineral soils of the Tuckerman Ravine shelter site on Mount Washington in New Hampshire. Results indicate that fencing would be a slow means of reestablishing ground-cover vegetation. Fertilization and liming were not very effective in producing an increase in ground vegetation.

*Federer, C. A.
1975. **Evapotranspiration.** Rev. Geophys. and Space Phys. 13: 442-445, 487-494.

This report to the International Union of Geodesy and Geophysics summarizes progress in research on evapotranspiration from 1970 through 1974, with emphasis on the United States contribution. The control of transpiration by plants through stomatal closure has been studied intensively, using diffusion porometers and pressure chambers. The rough surface of forests increases stomatal control of transpiration and increases interception loss of rain, when compared with lower plant covers.

*Frost, Richard E., and Hollis R. Large.
1975. **Pallet repair and salvage.** USDA For. Serv. Res. Pap. NE-323. 7 p.

Efficient unit-load handling with permanent pallets requires a well-organized pallet-repair program. To provide basic information on pallet damage that could be used in establishing repair standards, 1,700 damaged pallets at four repair facilities were inspected. All damage was recorded by type, severity, and location. This survey determined that missing deckboards at the ends of the pallet account for more than 50 percent of the total deck damage, and longitudinal breaks and splits outside the stringer notches account for more than 80 percent of the total stringer damage.

*Gabriel, William J.
1975. **Allelopathic effects of black walnut on white birches.** J. For. 73: 234-237, illus.
Heavy mortality and poor growth among repeated plantings of white birches were associated with toxic conditions produced by black walnut trees. Variation in response to toxicity was observed. Lethal effects were most prominent in the immediate vicinity of residual black walnuts, but some individuals survived in these areas, suggesting differences among trees in their levels of toxin tolerance. Birch trees were larger at greater distance from the source of toxicity, indicating a relationship between growth inhibition and toxin concentrate.

*Galford, Jimmy R.
1975. **Red oak borers become sterile when reared under continuous light.** USDA For. Serv. Res. Note NE-205. 2 p.
Red oak borers, *Enaphalodes rufulus* (Haldeman), reared under continuous light for 12 weeks, became sterile. Sterility is thought to have been caused by light destroying vitamins essential for fertility.

*Garrett, Lawrence D., Howard Duchacek, Frederick M. Laing, and James W. Marvin.
1975. **Test results of a maple sap preheater and modified oil burner arch with wood chips.** Natl. Maple Syrup Dig. 14(1): 14-15.
Conventional sap evaporators are only 50 to 65 percent efficient. Installation of maple sap preheaters on conventional open-pan syrup evaporators increased efficiency by 15.5 percent. Also, the study determined stack losses to be 14 to 20 percent, with an additional 7 percent loss to vaporizing water contained in fuel. Increases in economic returns to operators using preheaters ranged from 10 to 12 percent. Pilot test of chip-fired evaporators revealed comparative fuel efficiency of 12 gallons of No. 2 fuel oil and 300 pounds of wood chips at 35 percent moisture.

*Garrett, Peter W., and H. C. Kettlewood.
1975. **Variations in juvenile oak.** USDA For. Serv. Res. Note NE-204. 4 p.
Data from research on 13-year-old trees in an oak planting in southeastern Pennsylvania indicate that survival and growth are not correlated with source latitude within all species tested. A complete listing of species and seed origins, along with performance of progenies, is presented for persons interested in oak improvement.

Gerhold, H. D., A. J. Long, and M. E. Demeritt, Jr.
1975. **Genetic information needed for metropolitan trees.** J. For. 73: 150-153.
A genetic information system, based on performance testing of trees in metropolitan regions, is needed because of deteriorating environments and the rapid inclusion of new species and clones into the trade. The proposed system offers a method for recognizing disease and adaptation problems before they become widespread. A survey indicated that municipalities and highway departments in the region invest $12 million annually in planting programs involving more than 300,000 trees.

*Gibson, Harry G., and Cleveland J. Biller.
1975. **A second look at cable logging in the Appalachians.** J. For. 73: 649-653, illus.
Cable logging, once used extensively in the Appalachians, is being reexamined to see if smaller more mobile systems can help solve some of the timber-management problems on steep slopes. A small Austrian skyline was tested in West Virginia to determine its feasibility for harvesting eastern hardwoods. The short-term test included both selection and clearcut harvesting. Both yarding costs and environmental effects were analyzed.

*Gill, John D., Jack W. Thomas, William M. Healy, James C. Pack, and H. Reed Sanderson.

1975. **Comparison of seven forest types for game in West Virginia.** J. Wildl. Manage. 39: 762-768.

Forest type was used for classifying observations of turkeys, gray squirrels, white-tailed deer, and ruffed grouse on an 8,100-hectare study area. All game counts differed from counts that would be expected if locations of game were independent of forest type. Counts were converted to ratios, and comparisons were made directly between all pairs of forest types for any game species and all species/type combinations.

Gore, William E., Glenn T. Pearce, and Robert M. Silverstein.

1975. **Relative stereochemistry of multistriatin (2,4-dimethyl-5-ethyl-6, 8-dioxabicyclo [3.2.1] octane).** J. Organ. Chem. 40: 1705-1708.

The relative stereochemistry of the four multistriatin isomers were investigated. Stereochemical assignments for the C-2 and C-4 methyl groups in the four isomers were dedetermined on the basis of chemical and spectrometric data.

*Gregory, Garold F., and Thomas W. Jones.

1975. **An improved apparatus for pressure-injecting fluid into trees.** USDA For. Serv. Res. Note NE-214. 6 p., illus.

Our original tree-injection apparatus was modified to be more convenient and efficient. The fluid reservoir consists of high-pressure plastic plumbing components. Quick couplers are used for all hose connections. Most important, the injector heads were modified for a faster and more convenient and secure attachment with double-headed nails.

Gregory, R. A., and J. A. Romberger.

1975. **Cambial activity land height of uniseriate vascular rays in conifers.** Bot. Gaz. 136: 246-253.

Consideration of the various possible types of cell division in the cambium and various facts of wood anatomy led to a working hypothesis: after a coniferous tree having wood with uniseriate rays is released from severe suppression and the radial growth rate suddenly increases, the height of the wood rays will also suddenly increase, but the number of rays per unit of tangential area will stay the same. The hypothesis was tested by analysis of wood samples and was found valid.

*Grisez, Ted J.

1975. **Flowering and seed production in seven hardwood species.** USDA For. Serv. Res. Pap. NE-315. 8 p.

Flowering and seed production of selected trees in northwestern Pennsylvania and southwestern New York were rated visually for several years. The seed crops of white ash and sugar maple were closely related to the amount of flowering, and flowering can be used to predict seed crops in those species. Seed-producing capacity was also related to other measured variables, but not closely enough to make them useful in predicting seed production. Consistency of seed production in species and individuals, and other aspects of seed production are discussed.

*Hanks, Leland F.

1975. **New tools for grading hardwood trees.** South. Lumberman 231(2872): 49-50.

An introduction to the U.S. Forest Service hardwood tree grades for factory lumber. Specifications for these tree grades are presented along with a lumber grade yield table. Tree valuation is discussed and an example is illustrated.

*Hanks, Leland F., and Margaret K. Peirsol.

1975. **Value loss of hardwood lumber during air-drying.** USDA For. Serv. Res. Pap. NE-309. 10 p.

Dry-lumber prices were applied to green and air-dried lumber that was measured with a dry-board rule. Values were summed by species, lumber grade, and thickness class. Differences between green and air-dried lumber value have been termed value losses and are given in dollars and in percentages. The percentages have been separated into loss due to shrinkage and loss due to degrade. Data for 10 hardwood species are included.

*Hart, Irving A.

1975. **Current management practices on the Hartford Municipal Watershed.** *In* Municipal Watershed Management Symposium Proceedings. USDA For. Serv. Gen. Tech. Rep. NE-13: 111-114.

Hartford has an upland reservoir gravity-flow system servicing 391,000 people, an average of 53 million gallons daily. Total watershed area is 133,664 acres, of which 30,424 are owned; practically all is forested. Employees number 56, including 11 uniformed patrolmen. The superintendent is a professional forester, assisted by a second forester and a full-time forestry crew of three men with modern equipment. Standing timber is marked and sold by bid under formal contract. Vegetative manipulation for improvement of water supply is minimal. An active recreation area is located on one reservoir not used for drinking water.

Hartley, Brent A.

1975. **Current management practices on the Baltimore Municipal Watersheds.** *In* Municipal Watershed Management Symposium Proceedings. USDA For. Serv. Gen. Tech. Rep. NE-13: 84-97, illus.

The City of Baltimore supplies water to an estimated 1.5 million people in a 215-square-mile service area. The City has developed three sources of supply and maintains three municipal watersheds. Management of Baltimore's watersheds differs from that of many others in the Northeastern States in that we harvest timber on our watersheds and operate our own sawmill. We have also tried to provide recreational opportunities.

Heagy, James F.

1975. **Current management practices on private municipal watersheds.** *In* Municipal Watershed Management Symposium Proceedings. USDA For. Serv. Gen. Tech. Rep. NE-13: 124-128, illus.

Since 1954, sawtimber, pulpwood, and mine props have been harvested from 17 forested watersheds in Pennsylvania. Drainage from 15 areas flows into reservoirs used as sources of supply serving 14 communities. Potable water delivered from 8 of these reservoirs is not filtered. The harvesting and cultural practices used in the upland oak and bottomland hardwood types are emphasized. Othe watershed programs discussed include recreational use, problem areas, and use of herbicides.

Healy, W. M., and E. J. Goetz.

1975. **Imprinting and video-recording wil turkeys—new techniques.** Wildl. Soc Northeast. Sect. Trans. 31: 172-182.

Managing brood range of turkeys require knowing the habits of free-ranging poults but poults with hens are difficult to observ in the wild. To overcome this problem, w hatched turkey eggs from game farm an wild stock, imprinted the poults to ourselves and observed poult behavior in the field Feeding rates and other behavior were quantified and used to evaluate various habitats Portable video-tape equipment allowed eas recording of many observations that woul have been difficult to record any other way This approach could be applied in man studies of animal behavior and ecology.

*Healy, William M., Richard O. Kimmel, an Ellen J. Goetz.

1975. **Behavior of human-imprinted an hen-reared wild turkey poults.** Natl. Wil Turkey Symp. Proc. 3: 97-107. San Antonio TX.

A general description of behavior patterns i given for human-imprinted and hen-reare wild turkey poults (*Meleagris gallopavo si vestris*) from hatching until 4 months of ag Poults fed primarily on insects during th first 6 weeks of life; and by the 11th wee plants accounted for about half the diet. Th behavior of hen-reared and human-imprinte poults indicated the dependability of huma imprinted turkeys for controlled experimen tation.

Hejnowicz, Z.

1975. **A model for a morphogenetic ma and clock.** J. Theor. Biol. 54: 345-362.

A model system is proposed in which mo phogenic waves of varying lengths but sim lar periods interact to form standing wav envelopes that serve as the basis of morph genic maps. Wave-based morphogenic ma are seen as underlying both patterns an rhythms in organisms. This theory arose from biophysical interpretation of extensive studies of the cellular basis of wavy grain patterns in wood.

*Herrick, Owen W.
1975. **A profile of logging in the Northeast.** Part I. Crew size and equipment investment. North. Logger 24(4): 14-15, illus.

Characteristics of logging operations in 14 Northeastern states are summarized to give an up-to-date look at the combinations of men, equipment, and activities involved in cutting timber and moving it from stump to mill.

*Herrick, Owen W.
1975. **A profile of logging in the Northeast.** Part II. North. Logger 24 (5): 20-21, illus.

A continuation of the above, giving summary data on area logged, volume removed, product value, and skidding and hauling distances, with a generalized composite profile of the logging jobs now being carried on in the region.

Hock, Winand K., and Frederick H. Berry.
1975. **Sycamore anthracnose.** U.S. Dep. Agric. Handb. 470: 88-91, illus.

Sycamore anthracnose, caused by the fungus *Gnomonia platani* Kleb., is the most serious disease of sycamore. The four distinct stages of sycamore anthracnose—twig, bud, shoot, and leaf blight—are discussed. The prevalence and severity of attack are governed by weather conditions—frequent rains and cool temperatures favor rapid spread. There are two control procedures: sanitation and chemical sprays.

Hooper, Robert G., E. Frank Smith, Hewlette S. Crawford, Burd S. McGinnes, and Vernon J. Walker.
1975. **Nesting bird populations in a new town.** Wildl. Soc. Bull. 3(3): 111-118, illus.

Within four types of suburban habitats, the densities of breeding birds seemed to be related directly to the cubic feet of space occupied by shrubs below 12 feet high; however this relationship did not explain the variation in bird densities between habitats. It was hypothesized that clumping of vegetation was of equal or more importance than amount of vegetation. A direct relationship was also found between the number of species per acre and the cubic feet of space occupied by shrubs below 12 feet; and an inverse relationship was found between breeding birds and percentage of the plot covered by asphalt, cement, and buildings.

*Hornbeck, James W.
1975. **Streamflow response to forest cutting and revegetation.** Water Resour. Bull. 11: 1257-1260, illus.

Experimental cuttings on two small hardwood-forested watersheds in New England showed that annual streamflow can be increased as much as 41 percent. Most of the increase occurred in summer and early autumn when additional streamflow is most needed. Revegetation caused the annual increases to nearly disappear within 4 years after complete forest clearing.

Hornbeck, James W., and C. Anthony Federer.
1975. **Effects of management practices on water quality and quantity: Hubbard Brook Experimental Forest, New Hampshire.** *In* Municipal Watershed Management Symposium Proceedings. USDA For. Serv. Gen. Tech. Rep. NE-13: 58-65, illus.

A hypothetical dialogue between forest hydrologists and a municipal watershed manager illustrates the knowledge gained from research at Hubbard Brook. When forest vegetation is cut, water yield increases, especially when it is most needed during critical low-flow periods in late summer and early autumn. Unless measures are taken to control regrowth, the water yield returns to pretreatment levels within several years.

*Hornbeck, J. W., G. E. Likens, R. S. Pierce, and F. H. Bormann.
1975. **Strip cutting as a means of protecting site and streamflow quality when clearcutting northern hardwoods.** *In* Forest soils and forest land management. North Am. For. Soils Conf. Proc. 4: 209-225, illus. Quebec.

Changes in vegetation and streamflow as a result of the first cycle of a progressive strip cutting in northern hardwoods were determined on a 36-hectare mountainous watershed in New Hampshire. Timber was harvested in October 1970 by clearcutting 25-meter-wide strips alternating with 50-meter-wide uncut strips.

Hornbeck, J. W., R. S. Pierce, G. E. Likens, and C. W. Martin.
1975. **Moderating the impact of contemporary forest cutting on hydrologic and nutrient cycles.** Assoc. Int. Sci. Hydrol. Symp. Publ. 117: 423-433, illus.

Smaller-than-anticipated water yield increases and lower ionic concentrations of streamwater after a progressive strip-cutting indicate that the impacts of complete harvest of all trees can be significantly moderated by changing the time span and configuration of the cutting.

Hornbeck, J. W., R. S. Pierce, and C. W. Martin.
1975. **Forest cutting in New Hampshire increases volume and ionic concentrations of streamflow.** *In* Forestry issues in urban America. Soc. Am. For. Proc. 1974: 195-199.

Effects on streamflow of three intensities of forest cutting have been determined in central New Hampshire by using the ecosystem approach and small hardwood-forested watersheds. Complete elimination of forest vegetation for a 3-year period increased annual streamflow by 32 percent and caused 3- to 50-fold rises in concentration of major stream nutrients.

*Houston, David R.
1975. **Beech bark disease.** J. For. 73: 660-663, illus.

Stands of American beech in Maine—severely damaged by the beech bark disease in the 1930s and 1940s—were surveyed in 1973-4. Both disease agents (the scale *Cryptococcus fagi* and the fungus *Nectria coccinea* var. *faginata*) are now endemic, but few trees are dying. Another scale *(Xylococculus betulae)* is also abundant on all size classes of trees. Beech has become more numerous since the disease because death of large trees released sprout thickets. As they grow, young trees will be more susceptible to the disease. The stage seems to be set for a new severe outbreak.

*Houston, David R.
1975. **Soil fumigation to control spread of** *Fomes annosus*: **results of field trials.** USDA For. Serv. Res. Pap. NE-327. 4 p., illus.

A field trial was made to test the hypothesis that a band of roots killed by soil fumigation with methyl bromide would block the underground spread of *Fomes annosus* from diseased trees to healthy trees. After 4 years, the fungus had crossed the fumigation line in only 2 of 11 infection centers in red pine plantations.

*Houston, David R.
1975. **Occurrence of basal canker of white pine in Maine.** Plant Dis. Rep. 59: 74-76, illus.

Basal canker of white pine was found in young plantings established as living snow fences along Interstate Route 95 in Maine. The ecological similarities between this situation and that described previously for development of the disease in north-central New York were remarkably comparable. The results indicate that factors leading to the disease complex are more common and widespread than realized formerly.

*Hoyle, M. C.
1975. **High yield birch—nurture and nourish.** North. Logger 24(1): 20, 21, 36, 37, 38, illus.

The increasing demands for wood are viewed against the srinking land base for growing timber in the upland forests of northern New England. The solution to this problem is generally proposed to be intensive management. One type of intensive management—plantation management of paper birch and yellow birch—is being pilot-tested in the field. Three-year results show growth increases 2-fold (yellow birch) and 4-fold (paper birch) over controls as a result of deep liming and complete fertilization. Harvestable trees are expected in 20 years.

*Huyler, Neil K.
1975. **Tubing vs. buckets: a cost comparison.** USDA For. Serv. Res. Note NE-216. 5 p., illus.

Equipment investment for tubing-vacuum systems was significantly less than that for bucket systems. Tubing-vacuum systems required about 22 percent less labor input, the major labor input being completed before sap-flow periods. Annual cost of operation was less for tubing-vacuum than the bucket system. Small tubing-vacuum operations showed more profit potential than small bucket operations. Also, tubing-vacuum operations showed a 28-percent increase in sap volume yield as compared to bucket systems.

*Jensen, Keith F.
1975. **Sulfur content of hybrid poplar cuttings fumigated with sulfur dioxide.** USDA For. Serv. Res. Note NE-209. 4 p.

Hybrid poplar cuttings were fumigated with sulfur dioxide ranging in concentration from 0.1 to 5 ppm for periods of 5 to 80 hours. At the end of the fumigation periods, the cuttings were harvested and the sulfur and chlorophyll contents of the leaves were measured. At 0.1 ppm and 0.25 ppm the sulfur content initially increased, but decreased as fumigation continued. At 3 ppm and 5 ppm the sulfur content of the leaves significantly increased, and foliar injury was apparent. No statistically significant change in chlorophyll content was observed.

Jensen, K. F., and T. T. Kozlowski.
1975. **Absorption and translocation of sulfur dioxide by seedlings of four forest tree species.** J. Environ. Qual. 4: 379-382, illus.

Rates of absorption of SO_2 and translocation of absorbed sulfur were measured in sugar maple, bigtooth aspen, white ash, and yellow birch seedlings. Initially, bigtooth aspen, a sensitive species, had the highest absorption rate; and sugar maple, a tolerant species, had the lowest. After 20 hours or more of fumigation, absorption rates declined in all species except white ash, which is intermediate in sensitivity. Sulfur was concentrated in the leaves initially but had been translocated throughout the plants by the 8th day.

*Jensen, Keith F., and Roberta G. Masters.
1975. **Growth of six woody species fumigated with ozone.** Plant Dis. Rep. 59: 760-762, illus.

White birch, yellow birch, bigtooth aspen, eastern cottonwood, Japanese larch, and white spruce seedlings were fumigated with 25 pphm ozone for 110 days. Height growth of the white birch seedlings was reduced, but not by a significant amount; growth of the other species was not affected. The number and size of white birch leaves were also reduced during the fumigation period.

*Johnson, Roy R.
1975. **Use of herbicides in timber—and reservoir—management programs.** *In* Municipal Watershed Management Symposium Proceedings. USDA For. Serv. Gen. Tech. Rep. NE-13: 167-169.

Herbicides *can* be used in timber- and reservoir management programs. Knowledge of herbicides, application methods, timing, and nature of the area to be managed will enable the land manager to control and manage watershed vegetation with minimum contamination of water and minimum impact on the environment.

Jones, Thomas W.
1975. **The Dutch elm disease: challenges and solutions in urbania.** *In* Forestry issues in urban America. Entomol. Soc. Am.. Proc. 1974: 124-127.

Dutch elm disease threatens to eliminate elms as a major shade and street tree species in the urban landscape. But this esthetic and economic catastrophy is not inevitable. Existing control measures could minimize tree losses in many situations, and recent research developments offer the possibility of even more effective and versatile Dutch elm disease control.

Jumper, Gene A., and William N. Cannon, Jr.
1975. **Spermatogenesis in the smaller European elm bark beetle,** *Scolytus multistriatus*. Entomol. Soc. Am. Ann. 68: 733-740.

Testicular volume of *Scolytus multistriatus* (Marsham) increased rapidly during the larval and early pupal stage, reached its maximum during the pupal stage, and decreased in the adult stage. Spermatocytes, spermatids, and spermatozoa were all found in the adult, indicating that spermatogenesis continues into this stage of development. Spermiogenesis was studied during the prepupal, pupal, and adult stages, using light and electron microscopy.

*Keiser, George M.
1975. **Using a sugar refractometer.** Natl. Maple Syrup Dig. 14(3): 16-17, illus.

Instructions on use of the refractometer for determining sugar concentration in maple sap.

Kiang, Y. T., and P. W. Garrett.
1975. **Successful rooting of eastern white pine cuttings from a 17-year-old provenance planting.** Northeast. For. Tree Improve. Conf. Proc. 22: 24-34, illus.

The rooting response of cuttings from 40 eastern white pines representing 7 geographic sources was studied. Timing the collection of cuttings was the most important factor in rooting success. Cuttings collected in early May rooted as much as 88.3 percent in 160 days. Cuttings collected as early as mid-January can be rooted with moderate success, but late April to early June should be considered the most favorable time for collecting cuttings in the northeastern United States.

*Kingsley, Neal P.
1975. **The forest-land owners of New Jersey. USDA For. Serv. Resour. Bull. NE-39.** 24 p., illus.

A statistical-analytical report on a mail canvass of the owners of privately owned commercial forest land in New Jersey. Statistical findings are based on responses by owners to a questionnaire. Trends in forest-land ownership and the attitudes and intentions of owners regarding reasons for owning forest land, timber management, timber harvesting, recreational use, etc., are discussed.

*Kingsley, Neal P., and James C. Finley.
1975. **The forest-land owners of Delaware.** USDA For. Serv. Resour. Bull. NE-38. 19 p., illus.

A statistical-analytical report on a mail canvass of the owners of privately owned forest land in Delaware, based on a study made in conjunction with the second forest survey of Delaware. Statistical findings are based on responses by owners to a questionnaire. Trends in forest-land ownership and the attitudes and intentions of owners regarding reasons for owning forest land, timber management, timber harvesting, and recreational use are discussed.

*Knutson, Robert G.
1975. **The highway market for mulch—an opportunity for bark producers.** North. Logger 23(12): 13,32-33.

Only a few state highway departments permit the use of bark mulch for roadside seeding and planting projects. But, because of the excellent performance of bark mulch in a variety of horticultural uses, more states may permit its use. The highway market for mulch has good potential for bark producers because it is a large-volume outlet, and the bark requires only minimum processing.

*Knutson, Robert G.
1975. **Trends in the highway market for wood products.** USDA For. Serv. Res. Note NE-210. 4 p., illus.

Forty-eight million cubic feet of wood products, worth about $50 million were used in the Nation's highway construction program in 1972. Expenditures for highway construction increased 2½ times from 1954 to 1972. The volume of wood products used in highway construction changed little during this period because other materials were substituted for wood products for both structural forms and structure members.

*Kochenderfer, James N., and Gerald M. Aubertin.
1975. **Effect of management practices on water quality and quantity: Fernow Experimental Forest, W. Virginia.** *In* Municipal Watershed Management Symposium

Proceedings. USDA For. Serv. Gen. Tech. Rep. NE-13: 14-24, illus.

Results of 22 years of forest hydrology research. Forest influences were measured on quantity and timing of streamflow and parameters of water quality such as turbidity, temperature, specific conductance, pH, alkalinity, and nutrient concentrations. It is not practical to manage forest land for both sustained increased water yield and merchantable timber products, yet forest land can be managed for a variety of uses without impairing water quality.

Konar, R. N.

1975. **In vitro studies on *Pinus* II. The growth and morphogenesis of cell cultures from *Pinus gerardiana*.** Phytomorphology 25: 55-59.

Pinus gerardiana cells were continuously cultured in a liquid suspension system. Growth was monitored by following increase in cell populations with a hemacytometer. When plated onto an agar medium under specified conditions, cells formed colonies that grew into callus masses. The latter could then be transferred to other agar media supplemented with coconut water, casein hydrolysate, and hormonal substances. Under suitable conditions root and shoot primordia differentiated in the callus masses.

*Kottke, Marvin W., Malcolm I. Bevins, Gerald L. Cole, Kenneth J. Hock, and Wilbur F. LaPage.

1975. **Analysis of the campground market in the Northeast. Report III. A perspective on the camping-involvement cycle.** USDA For. Serv. Res. Pap. NE-322. 35 p.

A report on a study of the national camping market, conducted in 1973, updating findings of a similar survey conducted in 1971. Based on a nationally representative sample of 2,213 households, the total camping market is estimated to include 14.3 million households of active campers, 6.1 million who are temporarily inactive, and 6.1 million who are potential additions to the market. A detailed analysis of the popular image of camping as held by each of the major segments of the market is included, and the reasons for permanent and temporary dropping out of the camping market are examined.

Krawczyszyn, J., and J. A. Romberger.

1975. **Wood grain patterns allow study of the time aspect of slowly migrating morphogenic waves in cambia trees.** Chronobiologia 2: Suppl. 1: 38-39. (Abstr., Soc. Chronobiology Int. Conf. 12, Washington, D.C.)

Earlier studies in Poland and at Beltsville established the general principles of migrating cambial domains and explained the anatomical basis of wavy grain and interlocked grain in wood. This study of interlocked grain patterns in *Nyssa* and *Liquidambar* provides a basis for interpreting interlocked grain as a long-term biological rhythm. The period of the rhythm is nearly constant at 10 to 12 years even in paired *Nyssa* stems of the same age but of greatly different growth rates.

*LaPage, Wilbur F., Paula L. Cormier, George T. Hamilton, and Alan D. Cormier.

1975. **Differential campsite pricing and campground attendance.** USDA For. Serv. Res. Pap. NE-330. 6 p.

Price differentials, including a premium for waterfront campsites and a preferential rate for state residents, were introduced at a New Hampshire state park in 1973. Total revenue increased by 61 percent. Permit data before and after the change showed that attendance by state residents increased significantly. The differentials did not produce longer or more frequent visits by state residents, nor a decline in the use of waterfront sites. Declines in visit length and party size appeared to be independent of fee policies.

*Larsen, David N., and David A. Gansner.

1975. **Pennsylvania's private woodland owners: an important group of decision-makers.** Pa. For. 66(1): 10-12.

Private noncorporate owners—farmers, small businessmen, white-collar workers, retirees and others—own three-quarters of Pennsylvania's woodlands. This paper describes the characteristics, attitudes, and actions of this important group of decision-makers and discusses their key role as suppliers of forest products and services.

*Larsen, David N., and David A. Gansner.
1975. **Simple models for estimating local removals of timber in the Northeast.** USDA For. Serv. Res. Pap. NE-319. 7 p., illus.

A practical method of estimating subregional removals of timber is applied to a typical problem. Stepwise multiple-regression analysis is used to develop equations for estimating removals of softwood, hardwood, and all timber from selected characteristics of socioeconomic structure.

*Leak, W. B.
1975. **Age distribution in virgin red spruce and northern hardwoods.** Ecology 56: 1451-1454, illus.

Age distributions of trees in virgin stands (by species) take one of three forms: Stable populations show a linear relationship between the logarithm of stem number and the logarithm of age; a concave age distribution indicates an increasing population; and a convex to bell-shaped distribution indicates a declining population. *P. rubens, A. balsamea, B. papyrifera* var. *cordifolia,* and *S. americana* all had linear age distributions in a virgin spruce-fir stand. In a virgin stand of northern hardwoods, *F. grandifolia* was stable, *A. saccharum* increasing, and *P. rubens* and *B. alleghaniensis* declining.

*Leak, William B., and Stanley M. Filip.
1975. **Uneven-aged management of northern hardwoods in New England.** USDA For. Serv. Res. Pap. NE-332. 15 p.

Three main aspects of uneven-aged management in northern hardwoods are discussed: (1) choice of cutting method, including selection, group selection and patch selection; (2) control of yields, which involves the establishment of structural goals, the control of marketing operations, and the prediction of allowable harvest; and (3) the transportation or removal of products—truck roads, skidroads, and harvesting precautions.

*Leak, William B., and C. Wayne Martin.
1975. **Relationship of stand age to streamwater nitrate in New Hampshire.** USDA For. Serv. Res. Note NE-211. 5 p.

Streamwater nitrate content of six watersheds during spring and summer was apparently related to stand age or age since disturbance. Nitrate concentration averaged 10.3 ppm right after cutting, dropped to a trace in medium-aged stands, and then rose again to a maximum of 4.8 ppm as stands became overmature.

*Leak, W. B., and D. S. Solomon.
1975. **Influence of residual stand density on regeneration of northern hardwoods.** USDA For. Serv. Res. Pap. NE-310. 7 p.

In a study of hardwood regeneration, experimental plots were treated to produce residual densities of 40, 60, 80, and 100 square feet of basal area per acre with 30, 45, and 60 percent sawtimber. After 9 years, numbers of stems and percentage of stocking were estimated for each species, and plots were rated for reproductive potential under different residual densities. Data from a 3-year patch cutting are given for comparison.

Lewis, F. B.
1975. **Dosage effect on target insect populations (short- and long-term).** *In* M. Summers (ed.), Baculoviruses for pest control: safety considerations. Am. Soc. Microbiol. p. 143-144.

The immediate direct effect of introducing *Baculoviruses* into pest populations for immediate control effects is contrasted with the long-range effect on populations due to virus carry-over and resultant population regulation over time. The long-term effect of the introduction of the virus of the European pine sawfly is contrasted with the short-term effect of the viruses of gypsy moth and several agricultural pests.

Little, Silas.
1975. **Japanese honeysuckle: persistent efforts required to combat this robust immigrant.** Brooklyn Bot. Gard. Handbk. Weed Control in Home Gard. [Plants and Gardens 31(2): 55.]

This paper, a revision of a 1967 article, describes for homeowners the growth of honeysuckle and possible measures of control: pulling by hand, bulldozing with a root-rake, mowing, and herbicides. Though effective herbicides are discussed briefly, the homeowner is advised to consult a responsible state agency on current status and permissible use of any chemical for honeysuckle control.

Little, Silas.
1975. **Book review of "Handbook of vegetation science. Part V. Ordination and classification of communities. Part VIII. Vegetation dynamics."** Torrey Bot. Club Bull. 102: 79-80.
The two volumes reviewed are the first ones published of an 18-part handbook prepared by an international committee of ecologists and phytosociologists to summarize current knowledge. In the reviewer's opinion, use of these books will be limited primarily to readers versed in the technical jargon, and their value is reduced by certain omissions and a few inaccuracies. Even so, the volumes will be highly valuable references for specialists.

*Lucas, Edwin L., and Philip A. Araman.
1975. **Manufacturing interior furniture parts: a new look at an old problem.** USDA For. Serv. Res. Pap. NE-334. 6 p., illus.
The yields of interior furniture parts from four manufacturing sequences were compared. In three of the sequences, gang-ripping was the first step; in the fourth, the lumber was crosscut first. Though the grade of lumber used affects the percentage yield of parts, the manufacturing sequence used does not—but it will affect the cost per part. The selection of the best method must be based on factors other than parts yield.

Lynch, J. A., E. S. Corbett, R. J. Hutnik.
1975. **Water resources.** *In* Clearcutting in Pennsylvania: 51-64. Pa. State Univ. Coll. Agric. Sch. For. Resour.
The factors influencing the quality and quantity of water yielded from forested lands are outlined. The effects of clearcutting on stream nutrient concentrations, water temperature, turbidity, water yield, and stormflows are evaluated. Recommendations are made for protecting water resources when clearcutting is used as a forestry practice.

Lynch, James A., W. E. Sopper, E. S. Corbett, and D. W. Aurand.
1975. **Effects of management practices on water quality and quantity: the Penn State experimental watersheds.** *In* Municipal Watershed Management Symposium Proceedings. USDA For. Serv. Gen. Tech. Rep. NE-13: 32-46, illus.
The results of phases one and two of a three-phase clearcutting experiment on a 106-acre watershed in central Pennsylvania are reported. Phase one involved removal of vegetative cover on 21.3 acres of a lower-slope portion of the watershed. Phase two consisted of clearcutting an additional 27.0 acres on a mid-slope portion of the watershed. Effects of these treatments on water quality, quantity, and streamflow timing have been evaluated.

Lynch, James A., William E. Sopper, and Edward S. Corbett.
1975. **Watershed behavior under controlled simulated rainfall.** Pa. State Univ. Inst. Res. Land and Water Resour. 71 p.
To investigate the hydrologic behavior and response of a small natural forested drainage basin, an irrigation system was designed and installed to apply a uniform amount of simulated rainfall to any or all parts of a 20-acre watershed. The effects of antecedent soil moisture and storm size on the disposition of simulated rainfall and storm-hydrograph characteristics were analyzed. The hydrologic behavior and response of the watershed to controlled applications of simulated rainfall were also evaluated.

*McCauley, Orris D., and George R. Trimble, Jr.
1975. **Site quality in Appalachian hardwoods: the biological and economic response under selection silviculture.** USDA For. Serv. Res. Pap. NE-312. 22 p.
The percentage value response after 12 years of selective cutting on low- and high-quality sites amounted to a 119-percent increase on

the low-quality site and 145 percent on the high-quality site. The low-quality site increased in value only $76/acre while the high-quality site increased $233/acre. Current trends in species composition indicate that selective cutting practices will change the species composition toward a climax stand favoring shade-tolerant, slower-growing, lower-valued species.

McGee, Charles E., and F. Bryan Clark.
1975. **Harvesting and reproducing yellow-poplar.** Hardwood Res. Counc. 3d Annu. Hardwood Symp. Proc.: 26-31.
The authors offer these guidelines: (1) Harvest the existing stand by clearcutting or group selection; if the cut is much less than an acre, other species will probably be interspersed with the poplar. (2) Whatever harvesting system is used, control leftover unmerchantable material, preferably using chemicals on undesirable species to reduce sprouting.

*McGinnes, E. A. Jr., and A. L. Shigo.
1975. **Electronic technique for detecting discoloration, decay, and injury-associated ring shake in black walnut.** For. Prod. J. 25(5): 30-32, illus.
A new approach for detecting discoloration, decay, and injury-associated ring shake in black walnut and other species is described. A wire probe energized with a pulsed electric current is inserted into a small hole drilled 8 to 10 inches into the tree, and the changing pattern of resistance readings indicates areas of sound wood or wood in various stages of discoloration and decay.

*Marquis, David A.
1975. **Seed storage and germination under northern hardwood forests.** Can. J. For. Res. 5: 478-484.
Seed in excess of 1 million per acre were found to be common, the number of seed of a particular species depending on the number of seed-bearing trees of that species in the overstory and on the length of time seed of that species will remain viable in the forest floor. Sugar maple, eastern hemlock, and American beech normally germinate the year after seed dispersal and do not remain viable in the forest floor. Black cherry, white ash, yellow-poplar, red maple, and birch normally germinate over a period of several years after dispersal; and storage in the forest floor for 2 to 5 years is common.

*Marquis, David A.
1975. **The Allegheny hardwood forests of Pennsylvania.** USDA For. Serv. Gen. Tech. Rep. NE-15. 32 p., illus.
A history of the changes that have occurred in the Allegheny hardwood forests of northwestern Pennsylvania from the days of the Indian through the era of white settlement and industrial development up to the present time. Both the problems now faced in regenerating new stands and the bounty of timber and deer now obtained from these forests had their origin in events that occurred many years ago.

*Marquis, David A., Ted J. Grisez, John C. Bjorkbom, and Benjamin A. Roach.
1975. **Interim guides to the regeneration of Allegheny hardwoods.** USDA For. Serv. Gen. Tech. Rep. NE-19. 14 p., illus.
Regeneration of Allegheny hardwoods is difficult to obtain because of excessive deer browsing on tree seedlings. Density of advance seedlings, density of competing plants, soil drainage, and the importance of esthetic and recreation uses affect the choice of silvicultural system and cutting procedure for obtaining satisfactory regeneration. The authors provide guides needed for evaluating the regeneration potential and prescribing the most appropriate treatment for cherry-maple stands on the Allegheny Plateau of Pennsylvania and New York.

*Martin, A. Jeff.
1975. **T-H-A-T-S: Timber harvesting and transport simulator.** USDA For. Serv. Res. Pap. NE-316. 31 p., illus.
A detailed description of a FORTRAN IV computer program for simulating a typical timber-harvesting operation. Designed as a user's manual, the paper includes program development and operation, instructions for use, and output from an example problem. Flow charts are also included.

*Martin, A. Jeff.
1975. **A first look at logging residue characteristics in West Virginia.** USDA For. Serv. Res. Note NE-200. 3 p.

In 1973 and 1974, the Forest Products Marketing Laboratory obtained some preliminary information about characteristics of logging residues in West Virginia. Sixteen 1-acre plots were measured in conjunction with a test of the line-intersect sampling method. Findings from the 16 plots showed that hardwood residue volumes ranged from 100 to 1,300 cubic feet per acre, an average of 467.

*Martin, A. Jeff.
1975. **REST: A computer system for estimating logging residue by using the line-intersect method.** USDA For. Serv. Res. Note NE-212. 4 p.

A computer program was designed to accept logging-residue measurements obtained by line-intersect sampling and transform them into summaries useful for the land manager. The features of the program, along with inputs and outputs, are briefly described, with a note on machine compatibility.

*Martin, A. Jeff.
1975. **Predicting logging residues: an interim equation for Appalachian oak sawtimber.** USDA For. Serv. Res. Note NE-203. 4 p.

An equation, using dbh, dbh^2, bole length, and sawlog height to predict the cubic-foot volume of logging residue per tree, was developed from data collected on 36 mixed oaks in southwestern Virginia. The equation produced reliable results for small sawtimber trees, but additional research is needed for other species, sites, and utilization practices.

Martin, A. Jeff, and Victor J. Rudolph.
1975. **Evaluating northern hardwood timber stand improvement opportunities in northern lower Michigan.** Mich. State Univ. Agric. Exp. Stn. Res. Rep. 267. 10 p., illus.

Data collected from 25 small woodlands were used as the basis for a decision-tree analysis of 20 timber-stand-improvement options facing each owner. The internal rates of return used to evaluate the options ranged from less than 1 percent to more than 20 percent, averaging 8½ percent over all owners for the best five alternatives.

Mazzone, H. M.
1975. **An analysis of serological studies on the nucleopolyhedrosis and granulosis (capsule) viruses of insects.** *In* M. Summers (ed.), Baculoviruses for insect pest control: safety considerations. Am. Soc. Microbiol. p. 33-38.

The need for better control of insecticides has placed the natural enemies of insects in a unique position. The nucleopolyhedrosis and granulosis (capsule) viruses seem eminently qualified as natural control agents for pest insects. The author evaluates the serological studies that have been conducted on these organisms and considers what action should be taken to hasten their use as regulators of insect populations.

Mazur, A. R., T. D. Hughes, and J. B. Gartner.
1975. **Physical properties of hardwood bark growth media.** Hortscience 19(1): 30-33.

Physical properties of various hardwood bark-soil mixes for containers were compared to a soil-peat-perlite mix. Bark-soil mixes containing a wide range of bark particle sizes were found to possess superior physical properties initially and remained satisfactory after a 13-month incubation period. However, bark-soil mixes were much less stable and deteriorated to a significantly greater extent. It was concluded that use of hardwood bark in golf green mixes is not feasible.

*Melhuish, J. H., Jr., and E. Hacskaylo.
1975. **Fatty acid composition of ectomycorrhizal fungi in vitro.** Mycologia 67: 952-960, illus.

Mycelia of five ectomycorrhizal fungi—*Hebeloma sarcophyllum*, *H. crustuliniforme*, *Suillus cothurnatus*, *Pisolithus tinctorius*, and *Cenococcum graniforme*—growing *in vitro* were analyzed for fatty acid composition by GLC and TLC methods. The major fatty acid in each fungus was a di-unsaturated 18-carbon acid; 16:0 and 18:0 fatty acids were also present in each fungus; and an 18:1 fatty acid was detected in all fungi except *S. cothurnatus*.

Moeller, George H.
1975. **The Delphi technique: an approach to identifying events that will shape the future of outdoor recreation.** *In* Indicators of change in the recreational environment—a national research symposium: 211-220. Pa. State Univ. HPER Ser. 6. University Park.

A critique of the Delphi research technique and an example of how it was applied in a study to probe for relevant technological, managerial, and institutional events that are likely to influence recreation-resource management to the year 2000. The technique was used to develop a consensus of expert opinion and stimulate thinking toward formulating policies to deal with future recreation-resource management problems.

*Moeller, George H., Gerald S. Walton, and Elwood L. Shafer, Jr.
1975. **Dimensions of recreation resource planning decisions.** Recreation Rev. 4 (2): 24-35, illus.

To determine the meanings of 10 concepts that are involved in most recreation resource decisions and to identify the roles that these elements play in the process, factor analysis of semantic differential data was used to build a structure of semantic space with three factor axes—harmony, activity, and conventionality. Statistical analysis revealed four groups of elements that operate in the decision process: physical characteristics; recreation supply opportunities; recreation demand pressures; and political influences.

Neely, Dan.
1975. **Sanitation and Dutch elm disease control.** *In* Dutch elm disease: 76-87. USDA For. Serv. Northeast. For. Exp. Stn.

Sanitation is an important factor in Dutch elm disease control programs. This paper describes some experimental studies upon which sanitation practices are based, discusses the practical application of these research studies, and details the effects of sanitation as a disease-control measure in a number of communities.

Nelson, James C., Benjamin A. Roach, O. Lynn Frank, and Wilber Ward.
1975. **Timber management.** *In* Clearcutting in Pennsylvania: 33-49. Pa. State Univ. Coll. Agric. Sch. For. Resour.

Clearcutting, properly prescribed and carried out, is not forest devastation but a standard forestry measure used as the best means of regenerating a forest stand under certain conditions. It promotes a higher proportion of intolerant species and, where reproduction is prompt, results in faster development of the new stand than any other cutting method. Its use will be necessary for Pennsylvania's citizens to obtain maximum benefits from their forests. This report lists cautions to be observed in its use and describes certain situations in which it should not be used.

Nolley, Jean W.
1974. **Christmas trees: A bibliography.** (1974 supplement) Am. Christmas Tree J. 19(2): 21-28.

1974 supplemental listing of published information on the Christmas tree industry.

Nolley, Jean W.
1975. **Christmas trees: A bibliography.** (1975 supplement) Am. Christmas Tree J. 19(2): 21-27.

1975 supplemental listing of published information on the Christmas tree industry.

*Northeastern Forest Experiment Station.
1975. **Dutch elm disease.** USDA For. Serv. Northeast. For. Exp. Stn. 94 p., illus.

Proceedings of the IUFRO (International Union of Forest Research Organizations) conference on Dutch elm disease, held at Minneapolis-St. Paul in September 1973.

*Northeastern Forest Experiment Station.
1975. **1974 at the Northeastern Station.** USDA For. Serv. Gen. Tech. Rep. NE-18. 48 p.

A summary report on highlights of research activities and accomplishments by the Experiment Station in 1974, including an annotated list of publications.

Northeastern Forest Experiment Station.
1975. **Hubbard Brook: an outdoor forest lab.** N.H. For. Notes Winter 1975-6 (124): 20-22, illus.

A generalized description of the Northeastern Station's Hubbard Brook Experimental Forest at West Thornton, N.H., and the research being carried on there in various land-, forest-, and water-management measures to see what effect they have on local forest and water conditions.

*Northeastern Forest Experiment Station.
[1975] **Green vistas . . . black diamonds.** Northeast. For. Exp. Stn. 7 p.

A folder based on a slide presentation, describing work being done by a team of Forest Service researchers at Berea, Ky., on reclamation of strip-mined lands.

*Northeastern Forest Experiment Station.
[1975] **How to kill your tree.** Northeast. For. Exp. Stn. 1 p.

A leaflet listing 16 ways (plant too deep, plant too shallow, overfertilize, etc.) in which a tree can be damaged or inhibited.

*Northeastern Forest Experiment Station.
[1975] **How to keep your trees healthy.** Northeast. For. Exp. Stn. 1 p.

A leaflet listing 14 ways to help keep a tree healthy.

*Northeastern Forest Experiment Station.
[1975] **How to treat wounds to prevent decay.** Northeast. For. Exp. Stn. 1 p.

A leaflet listing eight ways to treat a tree wound to minimize decay and help the tree remain healthy.

*Parker, Johnson, and Roy L. Patton.
1975. **Effects of drought and defoliation on some metabolites in roots of black oak seedlings.** Can. J. For. Res. 5: 457-463, illus.

In two separate experiments, starch levels in roots were lower in defoliated watered black oak seedlings than in undefoliated watered seedlings. Starch in unwatered undefoliated seedlings was lower only when drought was severe. Drought and defoliation together resulted in lower starch levels than either one alone. Reducing sugars, several amino acids, and certain phenolics were higher in unwatered seedlings than in undefoliated watered ones. Catechin was lower in defoliated than in undefoliated seedlings regardless of watering. Fertilizer additions resulted in lower carbohydrate levels.

Patric, James H.
1975. **Announcement: report on lysimeter studies at San Dimas Experimental Forest.** For. Sci. 21(2): 195.

Announces the availability of a 143-page report on the lysimeter studies conducted at San Dimas from 1938 to 1960—the most extensive lysimeter study carried out in the country. The report is available from the author.

*Patric, James H., and David W. Smith.
1975. **Forest management and nutrient cycling in eastern hardwoods.** USDA For. Serv. Res. Pap. NE-324. 12 p., illus.

The literature was reviewed for reports on nutrient cycling in the eastern deciduous forest, particularly with respect to nitrogen and effects of forest management on the nutrient cycle. The nutrient content of the forest stand is a relatively small part of the total nutrient pool contained in soil. Under present practices of harvesting wood on a 50- to 100-year rotation, nutrient deficiency as a result of crop removal seems unlikely on most forest land.

*Patric, J. H., and W. R. Studenmund.
1975. **Some seldom-reported statistics on precipitation at Elkins, West Virginia.** W.Va. Agric. & For. 6(2): 14-16.

Start and stop times for precipitation were tabulated to the nearest hour from records on file at the Elkins airport. Graphical analysis showed that storms are most likely to occur between midnight and sunrise. Spells of wet or dry weather seldom persist for longer than 1 week, rarely for 2 weeks. Measurable precipitation can be expected during 1 day in 3 at the airport. Similar relationships can be computed from data on file at any National Weather Service installation having a recording rain gage and a full-time observer.

Payne, Brian R., and Richard M. DeGraaf.

1975. **Economic values and recreational trends associated with human enjoyment of nongame birds.** *In* Symp. Manage. For. and Range Habitats Nongame Birds Proc. USDA For. Serv. Gen. Tech. Rep. WO-1: 6-10. Washington DC.

Total direct expenditures for the enjoyment of nongame birds in 1974 were estimated to be $500 million. Expenditures for birdseed, binoculars, and camera equipment constituted 95 percent of the total. Continued moderate growth is predicted.

Payne, Brian R., Richard C. Gannon, and Lloyd C. Irland.

1975. **The second-home recreation market in the Northeast.** U.S. Dep. Inter. Bur. Outdoor Recreation. 27 p.

Recent rapid growth in construction of second homes has had great impacts on rural areas, accelerating change in land use out of farming and forestry. Economic effects on local communities have probably been positive; social and environmental effects may be negative. Policy issues and possible responses are identified.

Peacock, John W.

1975. **Research on chemical and biological controls for elm bark beetles.** *In* Dutch elm disease: 18-49. USDA For. Serv. Northeast. For. Exp. Stn., Upper Darby, Pa.

Past and current elm-bark-beetle research, as well as current beetle-control recommendations, are discussed. Current research on insecticides, parasites and other biological control agents, feeding stimulants and deterrents, attractants, and male sterilization are highlighted in the discussion.

Peacock, J. W., and R. A. Cuthbert.

1975. **Pheromone-baited traps for detecting the smaller European elm bark beetle.** USDA Coop. Econ. Insect Rep. 25(24): 497-500.

A simple and efficient beetle-detection system is described that utilizes pheromone-baited traps. Included is a discussion of the significance of trap catches in determining beetle distribution and abundance.

Peacock, J. W., R. A. Cuthbert, W. E. Gore, G. N. Lanier, G. T. Pearce, and R. M. Silverstein.

1975. **Collection of Porapak Q of the aggregation pheromone of** *Scolytus multistriatus* **(Coleoptera: Scolytidae).** J. Chem. Ecol. 1(1): 149-160, illus.

The attractive volatiles in the air around virgin female smaller European elm bark beetles tunneling in elm logs can be collected by passing the air through a column of Porapak Q. These volatiles can be removed by Soxhlet extraction with hexane, yielding an extract that is attractive to in-flight beetles. Analyses of this and an extract of virgin female frass indicate that the aeration extract contains active chemicals that are not in the extract of frass.

Pearce, G. T., W. E. Gore, R. M. Silverstein, J. W. Peacock, R. A. Cuthbert, G. N. Lanier, and J. B. Simeone.

1975. **Chemical attractants for the smaller European elm bark beetle** *Scolytus multistriatus* **(Coleoptera: Scolytidae).** J. Chem. Ecol. 1(1): 115-124, illus.

The secondary attractant for the smaller European elm bark beetle is a mixture of three compounds: (—)4-methyl-3-heptanol (I); 2, 4-dimethyl-5-ethyl-6, 8-dioxabicylo (3.2.1) octain (II); and (—)α-cuberbene (III). The novel structure assigned to compound II was confirmed by synthesis. All three compounds were isolated from volatile compounds collected on Porapak Q by aerating elm bolts infested with virgin female beetles.

Pennock, Rogert [Roger], Jr., Gene W. Wood, Paul W. Shogren, Jr., Kenneth Reinhart, Vernal C. Miles, Paul Younkin.

1975. **The forest soil.** *In* Clearcutting in Pennsylvania: 21-32. Pa. State Univ. Coll. Agric. Sch. For. Resour.

Effects of different timber-harvesting methods on erosion, compaction, temperature, moisture, and nutrient content of forest soils are reviewed. Erosion and soil compaction are mainly confined to skidtrails and hauling roads. Clearcutting may increase summer soil temperatures as much as 60°F and may cause some seedling mortality in winter. By reducing transpiration it may increase streamflow for 5 years or more. It apparently does not cause serious or irreplacable nutrient losses in Pennsylvania, but care should be taken to insure prompt revegetation.

*Plass, William T.
1975. **An evaluation of trees and shrubs for planting surface-mine spoils.** USDA For. Serv. Res. Pap. NE-317. 8 p.

Fifty-five tree and shrub species were evaluated on two surface-mine sites in eastern Kentucky. After 4 years' growth, comparison of survival and growth was used to identify the promising species for planting on acid surface-mine spoils. Three species of birch and three *Eleagnus* species survived and grew well on a range of sites. Noncommercial tree species and shrubs adapted to acid surface-mine spoils included silktree, tree-of-heaven, French tamarisk, Japanese fleeceflower, and Amur privet.

*Pogge, Franz L.
1975. **Sassafras for wildlife.** Pa. Game News 46(7): 17-19, illus.

Sassafras is a highly preferred food for deer, rabbits, and several other mammals, and for many game and nongame birds. This nontechnical paper tells how people have used sassafras since the 16th century, how sassafras grows and reproduces, and gives management recommendations. For propagating sassafras, root cuttings are best.

*Pottle, William H., and Alex L. Shigo.
1975. **Treatment of wounds on** *Acer rubrum* **with Trichoderma viride.** Europ. J. For. Pathol. 5: 274-279, illus.

Wounds on 90 *Acer rubrum* trees were inoculated with *Trichoderma viride* in July and August 1973 to determine the effect of the fungus on the development of decay. The trees were 45 years old and 15 cm diameter at 1.4 m above ground. Each tree had 12 wounds, 1.4 cm in diameter and 5 cm deep. After a year, 28 trees were harvested and isolations were made from the discolored and decayed wood associated with each wound. *Trichoderma viride* was reisolated from all wounds that were inoculated with it. Hymenomycetes were isolated frequently from decayed wounds not inoculated with *T. viride.* No Hymenomycetes were isolated from wounds inoculated with *T. viride.*

Purchasing World.
1974. **How pallets stand.** Purch. World 18(9): 68.

Although the supply of wooden pallets has improved, it is expected to remain snug over the next few years. It is suggested that pallet users take a closer look at the economics of pallet use. Pallet life increases much faster than price, up to $10 per pallet. Therefore better and more expensive wooden pallets cost less per use. Compared with other materials, wooden pallets still offer a hard-to-beat economic advantage.

Rast, Everette D.
1975. **Preliminary hardwood log veneer grades for yellow birch and sugar maple face veneer.** Hardwood Res. Counc. 3d Annu. Hardwood Symp. Proc.: 84-94, illus.

Each veneer mill generally has its own veneer-log grading system containing 2 to 6 grades. Some are similar, but many differ significantly. The proposed system is an initial attempt to correlate face-veneer yields with exterior log characteristics for yellow birch and sugar maple. The preliminary system separates the logs into 3 grades based on the yield of 2 Faces Sound and Better dry veneer.

Reinhart, Kenneth G.
1975. **Throughout the Northeast—an overview.** *In* Municipal Watershed Management Symposium Proceedings. USDA For. Serv. Gen. Tech. Rep. NE-13: 79-83, illus.

Forest watershed research has shown how management practices in the Northeast affect water quality (sediment, temperature, and nutrients), water yield, and stormflow. It has demonstrated how water quality can be protected and overland flow controlled. It has not yet shown how vegetation management can be used in a practical way to achieve the big potential for increased water yield.

*Richenderfer, James L., William E. Sopper, and Louis T. Kardos.

1975. **Spray-irrigation of treated municipal sewage effluent and its effect on the chemical properties of forest soils.** USDA For. Serv. Gen. Tech. Rep. NE-17. 24 p., illus.

Several forested areas on two soil types at the Waste Water Renovation and Conservation Project at The Pennsylvania State University were irrigated with treated municipal sewage effluent for 9 years (1963-71). Soil samples were collected to a depth of 5 feet in 1963, 1967, and 1971. These samples were analyzed to determine if any significant changes had occurred in the chemical properties of the soils as a result of the effluent irrigation. No detrimental effects were observed.

Riddle, Jane.

1975. **Opportunities for reclaiming strip-mined forest lands.** For. Farmer 35(4) : 6-8, illus.

A generalized description of the research being carried on at the Northeastern Station's research center at Berea, Ky., encompassing more than 60 studies by a team of researchers in forestry, soil science, geology, engineering, hydrology, biology, range management, wildlife management, microbiology, and economics.

Roach, Benjamin A.

1975. **Foreword.** *In* Clearcutting in Pennsylvania: ix-xii. Pa. State Univ. Coll. Agric. Sch. For. Resour.

This introduces a committee report describing the impacts of clearcutting on six major forest resources of Pennsylvania. It tells why the committee was organized and what it hoped to accomplish, and defines the type of clearcutting that was examined in detail in the rest of the report.

*Roach, Benjamin A.

1975. **Scheduling timber cutting for sustained yield of wood products and wildlife.** USDA For. Serv. Gen. Tech. Rep. NE-14. 13 p., illus.

Maintaining stable wildlife populations throughout eastern hardwood forests will require adjusting and regulating timber age classes by much smaller units of land (approximating the home ranges of the species involved) than would be needed for sustained yield of timber alone. The key to successful regulation for combined timber and wildlife production, with minimum impact on costs and timber yields, is long-term planning of cutting schedules and comparison of yields under alternative schedules for small units of land.

*Romberger, J. A., and C. A. Tabor.

1975. **The *Picea abies* shoot apical meristem in culture. II. Deposition of polysaccharides and lignin-like substances beneath cultures.** Am. J. Bot. 62: 610-617.

Shoot apical meristems of *Picea abies* growing as organ cultures release soluble precursors of polysaccharides and lignin-like substances. The precursors diffuse into or through supporting cellulose ester filter membranes and are condensed and deposited as insoluble products at sites remote from living cells. Little deposition occurs beneath a dialysis membrane. The system may be useful in studying synthesis of cell wall components and control of shoot apical development.

*Sanderson, H. Reed.

1975. **Den-tree management for gray squirrels.** Wildl. Soc. Bull. 3(3) : 125-131.

Den requirements of gray squirrels *(Sciurus carolinensis)* and den-formation processes are reviewed. One squirrel per 4 acres is suggested as a minimum population goal. At least one den per 2 acres—suitable for winter shelter and litter rearing—is recommended to compensate for interspecies competition for and inadequate distribution of dens. Options at four different levels of management intensity are discussed, although designed for even-aged forests, the more intensive of these options can be applied in any forest stand where dens are needed.

Sarles, Raymond L.

1975. **New equipment for bark application.** For. Prod. Res. Soc. Tech. Options in Bark Util. Proc. P-73/74-11: 7-24.

Though shredded bark performs well as a mulch over grass seedings, the lack of equipment to apply it at low cost, and general unavailability of bark, keep bark from being specified and used more widely in the East. These problems are discussed, with particular emphasis on equipment. Machine-design features and performance specifications are prescribed for new bark application equipment. Four prototype machines now under test are described.

*Seegrist, Donald W.
1975. **A multivariate model and statistical method for validating tree grade lumber yield equations.** USDA For. Serv. Res. Pap. NE-320. 20 p.

Lumber yields within lumber grades can be described by a multivariate linear model. A method for validating lumber-yield prediction equations when there are several tree grades is presented. The method is based on multivariate simultaneous test procedures.

Shafer, Elwood L., Jr.
1975. **The impact of human needs on the natural environments for recreation.** *In* Indicators of change in the recreational environment—a national symposium: 328-334. Pa. State Univ. HPER Ser. 6. University Park.

The need to incorporate man-environment relationships into public land-use policy decisions is discussed. The model of Spaceship Earth provides a framework within which to develop greater public awareness, understanding, and action programs to solve environmental problems. Broad-scale land-use planning cannot be undertaken until a working model of Spaceship Earth has been developed based on biological, political, social, and physical relationships defined through research.

*Shigo, Alex L.
1975. **Biology of decay and wood quality.** 2nd Int. Congr. Plant Pathol., Sess. Wood Prod. Pathol. Proc. 15 p., illus. Springer-Verlag, Berlin.

A model of the decay process has been developed, based on events from time of tree wounding to total decomposition of wood, including (1) host response, (2) invasion by pioneer organisms, and (3) decay of dead cells. Electrical engineering techniques and tools are now being used as aids to understanding the biology of decay in trees and wood products.

*Shigo, Alex L.
1975. **Heartwood and discolored wood.** North. Logger 25(2): 28-29, illus.

Heartwood is wood changed by normal aging processes. Discolored wood is wood changed as a result of injuries. Differences between heartwood and discolored wood are described.

*Shigo, Alex L.
1975. **Wood decay.** *In* McGraw Hill Yearbook of Science and Technology: 417-419, illus.

A new concept about how decay begins and develops in wood is described. The decay process is no longer seen as a simple relationship between wood and fungi, but as a complex succession of events that involve chemical reactions, bacteria, different kinds of fungi, and discoloration. Research on this new concept has revealed the unique ways in which a tree reacts to its wounds by sealing off the affected tissues. Even though a tree may be rotten at the core, it may still live on to produce healthy new wood for a long time.

*Shigo, Alex L.
1975. **Compartmentalization of decay associated with *Fomes annosus* in trunks of *Pinus resinosa*.** Phytopathology 65: 1038-1039.

Decay associated with *Fomes annosus* in 26 *Pinus resinosa* trees was compartmentalized in the trunks. The decay was confined to the wood present in the trunk at the time the fungus grew from the root into the root collar. The new wood that continued to form in the trunk was not infected. The healthy wood was associated with vigorous lateral roots.

*Shigo, Alex L., and Paul Berry.
1975. **A new tool for detecting decay associated with *Fomes annosus* in *Pinus resinosa*.** Plant Dis. Rep. 59: 739-742, illus.

An electrical meter that produces pulsed current and measures electrical resistance of wood to it detected decay associated with *Fomes annosus* in *Pinus resinosa.* Detection was based on the resistance pattern recorded as a special probe tip came in contact with decayed wood and resin-soaked wood. Resin-soaked wood had high resistance, and decayed wood had low resistance. A pattern of both high and low measurements as the probe was inserted into the tree indicated infection by *Fomes annosus.* Patterns of measurements that did not change abruptly indicated sound healthy wood.

Shigo, Alex L., and David Carroll.
1975. **What's the name of that tree?** Reader's Digest 107 (641): 155-162, illus. [September 1975.]

Brief generalized descriptions of America's foremost tree families; text and captions based on information from Shigo, illustrations by Carroll.

Shigo, Alex L., and Edwin vH. Larson.
1975. **Anatomy of a wound.** Weeds, Trees and Turf 14(7): 20-22, illus.

City trees are especially vulnerable to wounding, and any wound can open the way to the complex processes that can cause decay within the tree. The authors describe how a tree reacts to a wound and how a succession of microorganisms are involved in the decay process. Suggestions for treating and caring for a tree after it has been wounded.

*Shiner, James William, and Elwood L. Shafer, Jr.
1975. **How long do people look at and listen to forest-oriented exhibits?** USDA For. Serv. Res. Pap. NE-325. 16 p., illus.

The time that visitors spent looking at and listening to exhibits at the Adirondack Museum in New York was compared with the time actually required for reading exhibit material and listening to taped messages. Time spent ranged from 15 to 64 percent of time actually required.

Shull, Kenneth E.
1975. **Meeting current and future drinking-water quality standards.** *In* Municipal Watershed Management Symposium Proceedings. USDA For. Serv. Gen. Tech. Rep. NE-13: 142-153.

Drinking-water standards, first adopted by the U.S. Public Health Service in 1914, have been endorsed by the American Water Works Association and are enforced by most state departments of health. The standards were revised in 1925, 1942, 1946, and 1962. Standards are again under revision, and this time an effort is being made to legislate them so they will legally apply to all waters throughout the country.

Smith, H. Clay, and N. I. Lamson.
1975. **Grapevines in 12- to 15-year-old even-aged Central Appalachian hardwood stands.** Hardwood Res. Counc. 3d Annu. Hardwood Symp. Proc.: 145-150.

Twelve- to 15-year-old even-aged hardwood stands on 3 site classes were examined for number of saplings with grapevines. On good sites (SI 70), 75 percent of these stems had grapevines; on excellent (SI 80) and fair sites (SI 60), 50 and 2 percent had grapevines respectively. Grapevines per acre averaged 897 on good sites, 456 on excellent sites, and 16 on fair sites. Good quality saplings averaged 33, 53, and 67 percent on good, fair, and excellent sites. Grapevine-related sapling damage was more serious on good and excellent sites than on fair sites. Grapevine control measures are recommended.

*Smith, H. Clay, and Paul M. Smithson.
1975. **Cost of cutting grapevines before logging.** USDA For. Serv. Res. Note NE-207. 4 p., illus.

To reduce damage to hardwood stems by grapevines, it is recommended that grapevines be cut near ground level several years before the harvest cutting. Cost of completing this practice on 117 acres supporting 22 vines per acre was found to be about $3.5 per acre.

*Solomon, Dale S.
1975. **A test of point-sampling in norther hardwoods.** USDA For. Serv. Res. Not NE-215. 2 p.

Plot- and point-sampling were compared wit a complete inventory of two different stand of northern hardwoods. Prisms with basal area factors of 5, 10, 20, 30, and 40 and a ¼-acre plot were used. Only the 5-factor prism gave a significantly different estimate. Therefore, a prism factor of 10 or greater is suggested for use in northern hardwoods.

Spencer, Bruce A.
1975. **Current management practices on metropolitan Boston's municipal watersheds.** *In* Municipal Watershed Management Symposium Proceedings. USDA For. Serv. Gen. Tech. Rep. NE-13: 105-110.

The Metropolitan District Commission is a state-municipal agency that directs an active management program to supply water, sewerage, park, and some police needs for 32 towns and cities of the metropolitan Boston area. Four major aspects of the management program are described: watershed management, regulation and control of management activities, silvicultural practices, and wildlife management proposals.

Spomer, L. Art.
1975. **Availability of water absorbed by hardwood bark soil amendment.** Agron. J. 67: 589-590, illus.

This laboratory investigation determined the availability of water absorbed by hardwood bark soil amendment. Water retention isotherms on a volumetric basis were determined on bark samples of seven different species with a water pycnometer and a thermocouple psychrometer. Available water was assumed to be the volume held between 0 and —15 bars. Hence, about three-fourths of the water absorbed by bark is unavailable to plants.

Staley, David H., William R. Holt, and William N. Cannon, Jr.
1974. **Necessary and sufficient condition for a model insect population to go to extinction.** Math. Biol. Bull. 36: 527-533, illus.

A necessary and sufficient condition on the parameters for a model population to become extinct is presented. The mathematical model describes an insect population with overlapping generations where the females are polyandrous and the males are subject to autosterilization. The relationship between the values of the parameters of the model and the time to extinction is illustrated.

Stern, E. George.
1975. **Design of pallet deckboard-stringer joints. Part II. Reinforced aspen pallet joints and aspen pallets.** Va. Polytech. Inst. and State Univ. Wood Res. and Wood Constr. Lab. Pallet and Container Res. Cent. Publ. 133. 24 p.

Aspen-pallet joints were tested for their static deckboard-stringer separation and shear resistance, and 48-by-40-inch aspen pallets were tested for their static stiffness and impact rigidity. The results obtained seem to justify the use of a large number of relatively light wood species that previously were considered poorly suited for this use.

Stern, E. George, and Walter B. Wallin.
1975. **Design of aspen pallet deckboard-stringer joints.** For. Prod. J. 25(2): 51-54.

Results of tests on the ultimate impact torsional and shear resistance and the torsional rigidity and shear stiffness of aspen pallet deckboard-stringer joints as well as the static stiffness and impact rigidity of 48-by-40-inch aspen pallets. These tests indicate that properly designed aspen pallets can be at least 1⅓ times as stiff and 1⅕ times as rigid as comparative oak pallets of the same basic design.

Stipes, R. J.
1975. **Chemical control of** *Ceratocystis ulmi* **—an overview.** *In* Dutch elm disease: 1-15. USDA For. Serv. Northeast. For Exp. Stn.

Chemical control of Dutch elm disease and its beetle vectors is an integral part of successful disease-control programs. This paper emphasizes the chemical management of the disease with fungitoxicants. Techniques for application of toxicants—including methods for foliar, bark, stem, and root administration—are described. The strengths and weaknesses of the various techniques are discussed.

Stuart, Gordon, and William M. Alden.
1975. **Current management practices on National forest watersheds: White Mountain National Forest.** *In* Municipal Watershed Management Symposium Proceedings.

USDA For. Serv. Gen. Tech. Rep. NE-13: 129-134, illus.

The Berlin, N.H., municipal supply is an example of current management practices on the White Mountain National Forest. Part of the Kilkenny Management Unit, this will be the first area under the current planning program to develop a fully integrated management unit for obtaining a good balance of resource use as related to land capability and resource demands. The unit has been and will continue to be managed for water, timber, wildlife, and recreation. Recreation use —primarily hunting, fishing, and off-road vehicle use—is not generally restricted. No campground development is planned, but hiking use is expected to increase.

*Timson, Floyd G.
1975. **Forwarders come to the Appalachian Mountains.** North. Logger 24(2): 14, 15, 36, 37, illus.

Discusses operation of an off-the-road log-moving vehicle in the Appalachians, based on a case study, and describes ability of the forwarder to work under mountain logging conditions. Data on machine availability.

*Timson, Floyd G.
1975. **Weight/volume ratios for Appalachian hardwoods.** USDA For. Serv. Res. Note NE-202. 2 p.

Weight/volume relationships are presented in both English and metric systems for 15 commercial species of Appalachian hardwoods. Two ratios are presented: weight of wood volume alone, and weight of wood plus bark.

*Trimble, George R., Jr.
1975. **Summaries of some silvical characteristics of several Appalachian hardwood trees.** USDA For. Serv. Gen. Tech. Rep. NE-16. 5 p.

The author summarizes the following silvicultural characteristics of a number of Appalachian hardwood species: shade tolerance, susceptibility to epicormic branching, susceptibility to frost damage, diameter-growth rates, and seed dormancy in the forest floor.

*Valentine, H. T., and R. W. Campbell.
1975. **A simulation model of gypsy moth-forest interaction.** For. Sci. 21: 233-238.

An empirically based simulation model produces estimates of gypsy moth egg-mass density, defoliation, and subsequent tree condition and mortality for the oak forests of New England. The assumptions and rationale of the model are described in detail. Probability distributions of expected defoliation produced by the model can be used in decision-making about gypsy moth suppression.

Vogel, Willis.
1975. **Requirements and use of fertilizer, lime, and mulch for vegetating acid mine spoils.** Natl. Coal Assoc. Symp. on Surface Min. & Reclam. Proc. 3: 152-170. Louisville, Ky.

Mulch, in addition to lime and N and P fertilizers, was required for successful establishment of grasses and legumes seeded on extremely acid spoils (pH 2.2 to 3.5) in eastern Kentucky. With only lime and fertilizer, a sparse vegetative cover (mostly grass) became established; but where a mulch of shredded bark also was applied, a good cover of grasses and legumes was established. The plants were rooted only in the layer of spoil into which the lime had been incorporated (2 to 4 inches deep). The mulch reduced evaporation and maintained moisture in this rooting zone.

Wagar, J. Alan.
1975. **Effectiveness in interpretation.** Interpreter 7(3): 6-11, illus.

Summaries of existing knowledge and new studies show that interpreters' effectiveness can be improved by (1) defining clear objectives, (2) using attention-holding techniques, and (3) evaluating the extent to which objectives are achieved.

Wallin, W. B., E. G. Stern, and J. J. Strobel
1975. **Pallet exchange-program research findings indicate need for pallet standards** Va. Polytech. Inst. and State Univ. Wood Res. and Wood Constr. Lab. Pallet and Container Res. Cent. Publ. 134. 12 p.

Findings of pallet-exchange-program re

search indicate that the performance of warehouse and exchange pallets depends on the quality of the pallet shook, the deckboard-stringer fasteners and fastening system, the construction design specifications, and the conditions of use. The two requirements of a successful pallet exchange system are guaranteed uniform-value pallets and an agency to provide the guarantee to the pallet user. To insure this, the pallets must be produced and procured under the auspices of a third-party inspection and certification system.

*Walters, Russell S.
1975. **Collecting maple sap with plastic pipelines and vacuum pumps.** Natl. Maple Syrup Dig. 14(3): 14-17, illus.

Plastic pipelines for collecting sugar maple sap work well and offer cost- and labor-saving advantages over the traditional buckets. Due to natural vacuum, the closed system outyielded the vented system and buckets. Attaching a vacuum pump to the closed system gave even greater sap-yield increases. Doubling the sap yield by using a vacuum pump is possible. The recommended system is the aerial or suspended closed pipeline, using droplines that are at least 18 inches long. Use of a vacuum pump is strongly recommended.

*Walters, Russell S., and H. Clay Smith.
1975. **Sugar maple sap volume increases as vacuum level is increased.** USDA For. Serv. Res. Note NE-213. 4 p., illus.

Maple sap yields collected by using plastic tubing with a vacuum pump increased as the vacuum level was increased. Sap volumes collected at the 10- and 15-inch mercury vacuum levels were significantly higher statistically than volumes collected at the 5-inch level. Although the 15-inch vacuum yielded more sap than the 10-inch vacuum, the difference was not statistically significant. An efficient vacuum system should have a vacuum level of at least 10 inches of mercury at the taphole.

*Wargo, P. M.
1975. **Lysis of the cell wall of *Armillaria mellea* by enzymes from forest trees.** Physiol. Plant Pathol. 5: 99-105.

Partially purified preparations of the enzymes chitinase and β-1, 3-glucanese, concentrated by ammonium sulphate precipitation from healthy stem and root tissue of sugar maple, red oak, black oak, and white oak lysed the hyphal walls of *Armillaria mellea*. The enzymes were extracted from the phloem of both stem and root, but yields, especially of chitinase, were usually higher from stem tissues. Presence of enzymes in healthy trees that can lyse the hyphal walls of *A. mellea* suggests a protective mechanism that may account for the resistance of healthy tissues to invasion by *A. mellea* and possibly by other microorganisms.

*Wargo, Philip M.
1975. **Estimating starch content in roots of deciduous trees—a visual technique.** USDA Forest Serv. Res. Pap. NE-313. 9 p. illus.

A visual technique for determining starch content in roots of forest trees, based on iodine-staining of starch granules, was compared with a chemical method. Although the chemical method was more precise, roots could be sorted with the visual method into groups that are probably biologically important. The visual technique is simple and can be adapted for use in the field.

Wargo, Philip M., and H. Richard Skutt.
1975. **Resistance to pulsed electric current: an indicator of stress in forest trees.** Can. J. For. Res. 5: 557-561, illus.

Resistance to pulsed electric current was measured in stem tissues of white, chestnut, black, and red oak trees that had been defoliated by the gypsy moth, and their resistance was compared with that of undefoliated trees. Resistance to pulsed current was affected by tree species, diameter, crown class, and crown condition. However, regardless of species, diameter, crown class, or crown condition, defoliated trees had higher resistances than undefoliated trees. The relationship of resistance to pulsed current and tree vigor is discussed.

*Wartluft, Jeffrey L.
1975. **Double-drum sawdust stove.** USDA For. Serv. Res. Note NE-208. 4 p., illus.

An inexpensive home-made stove for burning loose sawdust is described. The stove, which is in common use in other parts of the world, can heat a room 20 feet square for 6 to 10 hours without tending.

*Wendel, G. W.
1975. **Stump sprout growth and quality of several Appalachian hardwood species after clearcutting.** USDA For. Serv. Res. Pap. NE-329. 9 p., illus.

Results of a 10-year study showed that stumps from 50- to 60-year-old red oak, black cherry, yellow-poplar, white oak, and chestnut oak trees sprouted vigorously. A high percentage of the dominant sprouts had good stem form, and many had excellent height and diameter growth. For all species, the proportion of stumps sprouting, number of sprouts per stump, and dominant-sprout height were not correlated with parent-tree vigor or parent-tree dbh. In red oak, sprouting was not related to season of cutting or site quality.

*Wendel, G. W., and F. C. Cech.
1975. **Recovery of herbicide-damaged eastern white pine.** Tree Planters' Notes 26(4): 18-20, illus.

About 3 percent of the white pine in a plantation were killed with 2,4,5-T. Several hundred other seedlings were damaged but have recovered and are growing well 3 years after treatment. Competing blackberries, greenbriers, and hardwood sprouts were killed or satisfactorily controlled; and 90 to 95 percent of the white pine are free to grow.

Wendel, G. W., and W. J. Gabriel.
1975. **Sugar maple provenance study: West Virginia outplanting 6-year results.** Northeast. For. Tree Improve. Conf. Proc. 22: 163-171.

As part of a range-wide sugar maple provenance study, seedlings from 15 provenances, each represented by 7 or 8 parent trees, were outplanted on a previously forested site on the Fernow Experimental Forest near Parsons, WV. After 6 years, survival was 97 percent. Tree heights ranged from 3.5 meters for the Lewis County NY provenance to 2.5 meters for the Cass County MN provenance. 1973 height growth ranged from 86.2 cm for the Franklin County VT provenance to 60.1 cm for the Cass County MN provenance. Incidence of cold injury was slight, as was damage from insects or diseases.

Wiant, Harry V., Jr., Miguel A. Ramirez, and Joseph E. Barnard.
1975. **Species composition as a predictor of site quality in mixed Appalachian hardwoods.** Hardwood Res. Counc. 3d Annu. Hardwood Symp. Proc.: 80-83.

The large numbers of tree species constituting Appalachian hardwood forests and their different ecological requirements seem to result in more-or-less distinct associations on sites of given quality. With data collected at more than 100 sample locations, tree species occurrences were treated as dummy variables and related to oak site index. A procedure for easy field application of the method is presented.

*Wilkinson, Ronald C.
1975. **Silicone antitranspirant increases susceptibility of eastern white pine to the white-pine weevil.** USDA For. Serv. Res. Pap. NE-326. 5 p., illus.

An attempt to increase oleoresin exudation pressure of eastern white pine, and hence resistance to the white-pine weevil, by using a silicone antitranspirant was unsuccessful. Internal tree water balance of treated trees was increased; but apical shoot growth of trees treated with the antitranspirant was retarded, and the trees were much more susceptible to white-pine weevil attack than other trees used as controls.

*Worley, David P.
1975. **Multiple use on municipal watersheds? One way to find an answer.** *In* Municipal Watershed Management Proceedings. USDA For. Serv. Gen. Tech. Rep. NE-13: 170-180, illus.

A sampling of the pressures for various multiple-use activities shows the complex situations created by multiple-use management, the concerns that municipal watershed managers should have, and the importance of preplanning, with particular reference t facilities shared by all the uses eventually selected as the watershed's multiple-use package. A five-step approach is described and illustrated by example for selecting multiple-use activities to feature and for adjusting a package of activities to match the funds available for shared facilities.

Zagórska-Marek, B.
1975. **Growth activity of fusiform initials in storeyed cambium.** Acta Soc. Bot. Pol. 44.

The development of interlocked grain in species having storied cambia poses questions of the mechanics of movement past one another of cell tips in adjacent stories. This was studied in samples of *Entandrophragma* wood. The history of cambial behavior was reconstructed by microscopic study of serial tangential sections. During the deposition of the wood of one left to right inclination change, the mean fusiform cell tip migrated laterally past 9 apposing tips in the adjacent storey. This was accomplished by development of forked tips, followed by preferential growth of one fork according to the prevailing orientational domain.

Zajaczkowski, S., and T. J. Wodzicki.
1975. **Inhibition and requirement of natural stimulator for cambial xylem production in isolated stem segments of** ***Pinus silvestris.*** Physiol. Plant. 33: 71-74.

When sterile isolated stem segments of *Pinus silvestris* are perfused with a defined culture medium, their cambia will continue to produce new cells for as long as 15 weeks. The segments can be sacrificed at any time and studied anatomically. Thus the effects of auxins, inhibitors, and other substances upon wood formation can be determined in a controlled isolated system. The method is being used to study control of cambial activity.

*Zerillo, Roger T.
1975. **A photographic technique for estimating egg density of the white pine weevil,** ***Pissodes strobi*** **(Peck).** USDA Forest Serv. Res. Pap. NE-318. 4 p., illus.

Compares a photographic technique with visual and dissection techniques for estimating egg density of the white pine weevil, *Pissodes strobi* (Peck). The relatively high correlations (0.67 and 0.79) between counts from photographs and those obtained by dissection indicate that the nondestructive photographic technique could be a useful tool for determining egg density.

*Zerillo, R. T., and J. D. Podgwaite.
[1975] **Meet the gypsy moth.** USDA For. Serv. Northeast. For. Exp. Stn. 16 p., illus.

This color publication illustrates photographically the life stages of the gypsy moth, *Lymantria dispar* (egg through adult). It was designed as a guide in identifying the insect's life stages as well as explaining its life cycle.

Headquarters of the Northeastern Forest Experiment Station are in Upper Darby, Pa. Field laboratories and research units are maintained at:

- Amherst, Massachusetts, in cooperation with the University of Massachusetts.
- Beltsville, Maryland.
- Berea, Kentucky, in cooperation with Berea College.
- Burlington, Vermont, in cooperation with the University of Vermont.
- Delaware, Ohio.
- Durham, New Hampshire, in cooperation with the University of New Hampshire.
- Hamden, Connecticut, in cooperation with Yale University.
- Kingston, Pennsylvania.
- Morgantown, West Virginia, in cooperation with West Virginia University, Morgantown.
- Orono, Maine, in cooperation with the University of Maine, Orono.
- Parsons, West Virginia.
- Pennington, New Jersey.
- Princeton, West Virginia.
- Syracuse, New York, in cooperation with the State University of New York College of Environmental Sciences and Forestry at Syracuse University, Syracuse.
- Warren, Pennsylvania.

Northeastern Forest Experiment Station.
1976. **1975 at the Northeastern Forest Experiment Station.** Northeast. For. Exp. Stn., Upper Darby, Pa.
39 p. (USDA For. Serv. Gen. Tech. Rep. NE-24)

A summary report on highlights of research activities and accomplishments by the Experiment Station in 1975, including an annotated list of publications.

(74/75):945.4:(047.1)

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1976. **1975 at the Northeastern Forest Experiment Station.** Northeast. For. Exp. Stn., Upper Darby, Pa.
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25-29 August 1975

Planned and presented by

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College of Environmental Science and Forestry,
State University of New York at Syracuse

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The Pinchot Institute for Environmental Forestry Research, Consortium for Environmental Forestry Research

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The Conference

by GORDON M. HEISLER, *and* LEE P. HERRINGTON, *Conference cochairmen; respectively research forest meteorologist, USDA Forest Service, Northeastern Forest Experiment Station, Pennington, N. J. 08534; and professor of meteorology, State University of New York College of Environmental Science and Forestry, Syracuse, N. Y. 13210.*

THIS IS A REPORT on the Conference on Metropolitan Physical Environment, held in August 1975 at Syracuse, N.Y., where some 160 scientists and planners met to discuss the use of vegetation, space, and structures to improve the amenities for people who live in metropolitan areas.

Nearly all the papers presented at the Conference are published in this Proceedings. A few of the papers were invited, but most were selected by session chairmen from abstracts submitted. Some presentations were the so-called "poster papers" that provide ample and easy opportunity for direct communication between the author and people particularly interested in the subject.

The conference was held at the Everson Museum in downtown Syracuse. Financial support was provided by the Pinchot Institute for Environmental Forestry Research, Northeastern Forest Experiment Station, Forest Service, U.S. Department of Agriculture. Facilities, local meeting arrangements, and publicity were coordinated by the State University of New York College of Environmental Science and Forestry, as a continuing education service. The American Meterological Society published the complete program in their Bulletin, supplied copies for use at the conference, and later published a conference summary in the Bulletin.

The Pinchot Institute for Environmental Forestry Research was established to develop the knowledge needed to solve problems of policy formulation, land planning, and forest and open-space land management in and around metropolitan areas. It conducts an interdisciplinary research program designed to improve urban living conditions through manipulation of urban vegetation systems.

The Pinchot program is a coordinated effort between the U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station, and the Consortium for Environmental Forestry Studies, which is an organization of nine northeastern universities and the Forest Service. The Consortium's Working Group on Urban Forest Amenities is one of eight technical groups through which Consortium research is organized.

The scientists in the Forest Amenities Group have strong interests in the meteorology and acoustics associated with trees and forests in metropolitan areas. Through their research, they are searching for ways to design more comfortable urban environments through manipulation of urban forest systems and open space.

Initial studies of the Amenities Working Group indicated a need for exchange of information and cooperation with other disciplines and with people in other roles — managers, planners, and designers of urban spaces. This conference on metropolitan physical environments was planned to help meet that need.

To broaden the scope of the conference, a number of persons outside the

Forest Amenities Working Group were recruited to serve on the conference program committee. The Conference was organized into eight sessions dealing with four subject areas: (1) urban meso- and micrometeorology, (2) acoustics, (3) air quality, (4) and qualitative aspects of metropolitan environments. The word "qualitative" was used to organize discussion related to the esthetics and function of metropolitan spaces, human behavior, planning, and design.

Conference attendees enjoyed several special events. The eminent ecologist, Pierre Dansereau, of the University of Quebec, set the tone for the conference with an inspiring keynote address at the Monday evening plenary session. Dr. Dansereau stressed the importance of viewing environmental problems holistically and described his conceptual model of global resource interrelationships.

The Wednesday evening banquet address by Paul M. Friedberg, director of the Urban Design Program, City College of New York, was both entertaining and informative. Mr. Friedberg dramatically emphasized the importance of considering human needs and behavior in the design of urban parks and outdoor gathering places. During breaks between sessions, walking tours of downtown Syracuse parks and plazas were led by landscape architecture student Margie Gershek.

In publishing these proceedings, it is the intent of the Northeastern Forest Experiment Station to show more clearly the role of trees in the context of the many physical and social variables of metropolitan environments. Although some of the papers do not deal directly with vegetation, all papers do provide valuable background information for the distinctly interdisciplinary concerns of the emerging field of urban forestry.

Program Committee

Cochairmen of the Conference were:

LEE P. HERRINGTON, State University of New York, College of Enviromental Science and Forestry; and

GORDON M HEISLER, USDA Forest Service, Northeastern Forest Experiment Station.

Other members of the program committee were:

DONALD D. DAVIS, The Pennsylvania State University (Air Quality Session Chairman).

DAVID DeWALLE, The Pennsylvania State University (Proceedings Editorial Committee).

CHRISTOPHER MACEY, State University of New York College of Environmental Science and Forestry ("Qualitative" Topics Session Chairman).

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ELWOOD L. SHAFER, JR., Northeastern Forest Experiment Station.

PETER W. SUMMERS, Environment Canada (Meteorology Session Chairman).

MESOSCALE METEOROLOGY OF METROPOLITAN REGIONS

Overview of Urban Climate

by ROSCOE R. BRAHAM, JR., *professor, Department of the Geophysical Sciences, University of Chicago, Chicago, Ill. 60637.*

ABSTRACT. The broad features of urban climate anomalies are described and explained by combining recent METROMEX data with those from prior studies. The urban heat island is well understood, and urban effects upon cloud nuclei and cloud microstructure are clearly observed and explained in part; but the causes of urban effects upon rainfall remain speculative.

IT IS APPROPRIATE that this conference begin with a session on meteorology. Not only are specific climatic effects associated with cities, but meteorological conditions determine the capacity of the atmosphere to transport, disperse, and scavenge pollutants and thereby influence the location and extent of pollution-related injury to plants and man. Moreover, wind and temperature are factors in the dispersal or ducting of sound pollution.

Urban climate is an old subject; published papers go back over 150 years. It is inevitable, therefore, that some of my material will be old-hat to some of you: to others it will provide an entree into the field. However, most of my remarks will center around Project METROMEX and will represent material that has appeared only in specialized publications and reports.

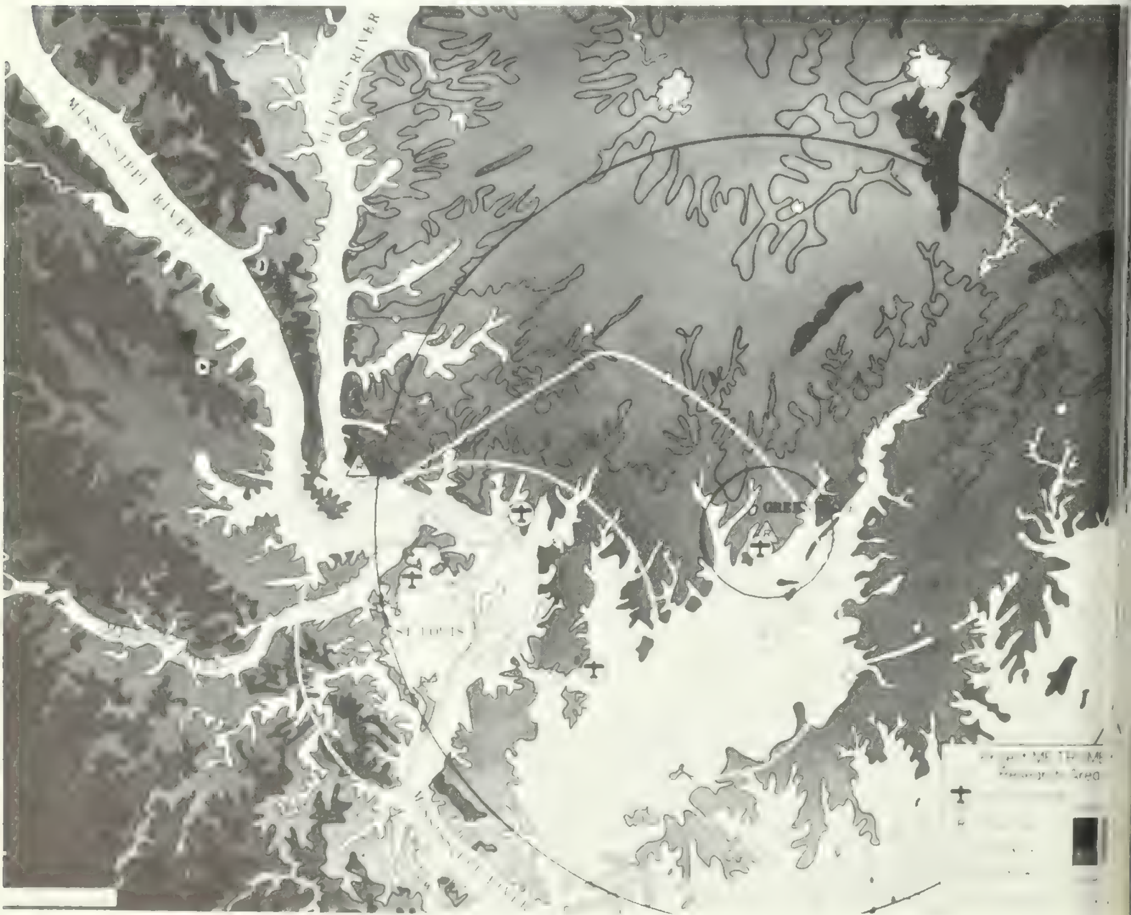
It was about 1968-69 that several scientists engaged in cloud-seeding research began to discuss the need for study of inadvertent modification of weather around large metropolitan areas. Out of this grew Project METROMEX, involving scientists from the Illinois State Water Survey, the University of Wyoming, the Argonne National Laboratory, and the University of Chicago. We undertook a study of the location and magnitude of anomalous weather fields around St. Louis in an effort to establish cause-and-effect relationships linking those fields to causal agents in the city, and to the extent possible to generalize and extend our findings to larger issues in society. Subsequently, we have been joined by scientists from the Battelle Pacific Northwest Laboratories, the Stanford Research Institute, the Sierra Nevada Corporation, and the NOAA Wave Propagation Laboratory.

The metropolitan St. Louis area was selected for study because it was large enough to have a significant pollution problem, yet small enough to be encompassed by a project of practical size. St. Louis has a long history of public concern over pollution; it was the subject of several prior meteorological studies; it has relatively light commercial air traffic, thus making research flights practical; it was considered to be relatively free of major topographic influences; and it was close enough to Illinois to justify expenditure of substantial amounts of state resources. In addition to support from the State of Illinois, METROMEX is supported by the National Science Foundation, the Energy Research and Development Administration, and the Environmental Protection Agency.

The subsequent choice of St. Louis for the EPA Regional Air Pollution Study (RAPS) has further indicated the appropriateness of St. Louis for such studies and should ultimately enhance the value of both projects. The geographical setting and centers of operations on Project METROMEX are shown in figure 1. Although this project is still in progress, there have been significant findings which, when added to prior data, allow us to determine many of the reasons for urban climate anomalies. Because of space limitations, detailed references to METROMEX publications are not given in this paper. Readers are referred to a recent summary of METROMEX findings and publications *(Principal Investigators of Project METROMEX 1976)*.

For some time it has been known that, in the absence of over-riding topographic influences, cities are warmer than surrounding rural areas. They also have more fog, cloud, and rain, while receiving less sunshine. Cities appear to be drier during summer and more moist

Figure 1.—METROMEX area in eastern Missouri and central Illinois.



during winter than the nearby rural areas. METROMEX has found an excess of thunderstorms and hail downwind of St. Louis.

What can be said about the probable causes of these urban climatic anomalies? Four characteristic differences between urban and rural areas are recognized as potential contributing causes for modifying weather around cities. These four factors are:

1. Contrasting thermal properties of urban-rural surfaces. Most cities abound in rock-like materials whose thermal conductivity and heat capacity are high relative to those of soil and plant materials that dominate the rural scene. These differences have profound effects on urban-rural temperature differences and local convection.
2. Greater aerodynamic roughness of built-up areas. The tall and irregularly spaced buildings of cities represent a much rougher surface, aerodynamically speaking, than do trees and low vegetation. This results in increased mixing (turbulence) and measurable convergence of the low level flow over cities.
3. Smaller amounts of water available for evaporation in cities. In rural areas most of the rainwater remains near the surface and is evaporated or transpired by plants. In cities, much of it is ducted away to nonurban areas for evaporation. The greater use of energy for evaporation results in lower rural temperatures.
4. Anthropogenic heat, gases, and particulates released over cities. Cities release large amounts of heat, gases, and particulates into the air over them. Only recently have we come to recognize the contribution of these to weather effects.

The relative importance of these four factors probably varies with the size and population of a city, its patterns of industry and land use, and with meteorological conditions, both ambient and recent past. We must anticipate that they contribute differently to different weather effects and that their effects combine in different ways depending upon season, time of day, and regional meteorological conditions.

URBAN HEAT ISLAND

One of the longest studied and best understood of the urban weather effects is the *Urban Heat Island.* The characteristics of urban areas invariably result in slight warming of air passing over them during daylight hours and in reduced rates of cooling at night. The result is a shallow pool, or "island" of warm air centered over the city and flowing off as an elevated plume in the downwind direction. (Exceptions are cities under marked topographic influences and in windy, cloudy periods.)

When well developed, the heat island maximizes over the most densely built-up parts of the city and decreases outward to a sharp gradient around the urban boundary. The maximum surface temperature differences between urban and rural areas usually occur at night, in fall or winter months, and during clear skies and light winds of anticyclonic weather conditions.

For those in other disciplines, I should explain that meteorologists use the term "surface" when referring to conditions in air 1 to 10 meters above ground level. The term "skin temperature" is used to denote conditions at the radiating surfaces, as seen by downward pointing radiometers.

Measurements by the Illinois State Water Survey, in METROMEX, show that the heat island at St. Louis is about what one would expect. Under clear to partly cloudy skies, it is best developed at 2000 and 0200 CDT, becomes broader but less intense at 0700 CDT, and is largely obscured by topographic factors at 1100 and 1500 CDT.

The diurnal variation of surface

temperature differs between urban and rural stations. A rural site warms more quickly, from a lower minimum, during the early part of the day, and cools more quickly during the afternoon and evening.

The diurnal pattern of skin temperatures of urban and rural terrain is different from that of air at low levels. Measurements by Dabberdt and Davis *(1974)*, using IR photometers on a low-flying airplane, showed that the maximum difference in skin temperatures at St. Louis occurred early in the afternoon on clear summer days but during night hours on winter days.

The intensities of heat islands increase with size of the city. Oke *(1973)* and Eagleman *(1974)* conclude that it varies with logarithm of population. Ludwig and Dabberdt *(1973)* propose a fourth root relationship. Landsberg *(1974)* shows that careful measurements will reveal local warming around even a few residential buildings.

Cloud cover and regional wind speed are important factors governing the development of heat islands. By altering radiation exchange between the surface and atmosphere, the effect of clouds is to reduce the heat island intensity *(Petersen 1969)*. Wind has the effect of ventilating a city and limiting the differences betwen urban and rural temperatures. Oke and Hannell *(1970)* summarize data on the critical wind speed above which a heat island is not usually detected, and show that the critical wind (U) was related to population (P) through the equation

$$U = 3.4 \log P - 11.6. \qquad [1]$$

In deducing causes for heat islands, it is useful to start by considering the thermal energy balance of the earth's surface, equation 2,

$$SW\downarrow + LW\downarrow + A = E + P + S + T + LW\uparrow. \qquad [2]$$

The energy sources for an area of the earth's surface consist of that portion of the solar radiation, SW↓, and atmospheric radiation, LW↓, which is absorbed by the surface, plus any anthropogenic heat released from terrain objects (A). These energy sources are balanced against the conversion of sensible energy into latent forms through evaporation and transpiration, E, and photosynthesis, P, the flux of sensible heat into the subsurface, S, and by flow of sensible heat into the atmosphere by diffusion, T, and IR radiation, LW↑.

Although all these terms contribute to the formation of heat islands, the most important appear to be energy used for evaporation and transpiration, flux of heat into the subsurface, and anthropogenic heat.

Evaporation is largely responsible for keeping rural temperatures lower on sunny days. Heat stored in urban surfaces during daytime, and returned to the air at night, is responsible for keeping urban areas warm long after radiation cooling dominates the rural scene.

The importance of anthropogenic heat has been debated; however, data compiled by Koenig and Bhumralker *(1974)* show that the urban-heat release in Manhattan exceeds the solar energy absorbed at the surface by a factor of 3.9. Even in an open park-filled city like Washington, D. C., the areal average heat release is equivalent to over 25 percent of the solar insolation.

STRUCTURE OF THE URBAN BOUNDARY LAYER

The heat island and surface roughness of urban areas combine to modify the atmospheric boundary layer from its upwind character. This modification is three-dimensional and varies with time of day and meteorological conditions. Observations of horizontal and vertical winds, temperatures, and water vapor, with sufficient accuracy and detail to delineate the urban boundary layer structure, are difficult to make and as yet inadequate to allow a complete description of it.

METROMEX studies show that the St. Louis heat island is measurable through the depth of the mixing layer. Temperature excesses of 1°K frequently are found as high as 800 m agl. During the summer days we find a mimimum in specific humidity with height-averaged deficits of 1 g kg^{-1} not unusual. These anomalous fields are displaced downward from the urban center by ambient winds. We sometimes find above the heat island a shallow cap of air slightly cooler than rural air at the same levels.

The top of the mixing layer at St. Louis domes up over the city in daytime, and morning rise-rates are faster than over rural areas. The mixing layer frequently undergoes a diurnal cycle as described in following paragraphs. Summer convective clouds appear earlier over the city and usually have higher bases than those over rural areas—up to 300 m in some cases.

Low level airflow at St. Louis is markedly perturbed by the city in light wind conditions. METROMEX data show that a frequent result is airflow convergence up to an average height of 1250 m with values as large as 0.5×10^{-4} sec^{-1} up to levels of 800 m agl. Measurements of atmospheric parameters and urban aerosol particles within and below cloud bases, plus results of tracer experiments, prove that air from the urban boundary layer feeds into and alters the properties of clouds. Measurements also show that clouds and rain are significant removal mechanisms for urban pollutants.

Numerical modelling suggests that the thermal excess at St. Louis is more important than surface roughness in raising the depth of the mixing layer, and under certain conditions, in displacing it downwind.

By combining these METROMEX observations with data from a number of other sources, we can outline the major features of the urban boundary layer during summer and fall convective weather conditions. Although this analysis is pointed particularly toward summer conditions at St. Louis, it should also serve as a point of departure for analyzing the boundary layer over other cities and during other seasons.

Before sunrise over rural areas one usually finds a deep radiation inversion. The inversion may be capped, or even replaced, by an isothermal layer if fog or heavy haze is present *(Pilie et al. 1975)*. Reduced vertical mixing across the inversion tends to decouple the winds from the surface resulting in light winds in the inversion and a sharp wind increase across it. Any shear-driven mixing layer will be quite thin.

Over both urban and rural areas, we may find considerable amounts of haze as a result of upward mixing (somewhere upstream) on previous days. Frequently the haze develops into layers along internal stable levels. The top of the haze may be very sharp, corresponding to a stable layer, and accompanied by a sharp drop in humidity. Other times the haze top will be ill-defined, merely thinning gradually with height.

Frequently, when the haze has a well-defined top, in early morning it will carry a thin stratus cloud layer formed through nocturnal radiational cooling from the haze. Meteorologists frequently call the entire haze layer, the "mixed layer" to differentiate it from the layer of active mixing, the "mixing layer" within it.

Over the city before sunrise, because of the heat island, any surface radiation inversion will be weak, perhaps limited to large air-drainage areas such as along river channels. The absence of a strong low-level inversion allows the wind to remain more tightly coupled to the surface, resulting in a turbulent mixing layer. At sunrise this layer may be 300 to 400 m thick and filled with smoke and haze; it may be capped with a weak elevated inversion. Above the surface mixing layer the haze and any stratus

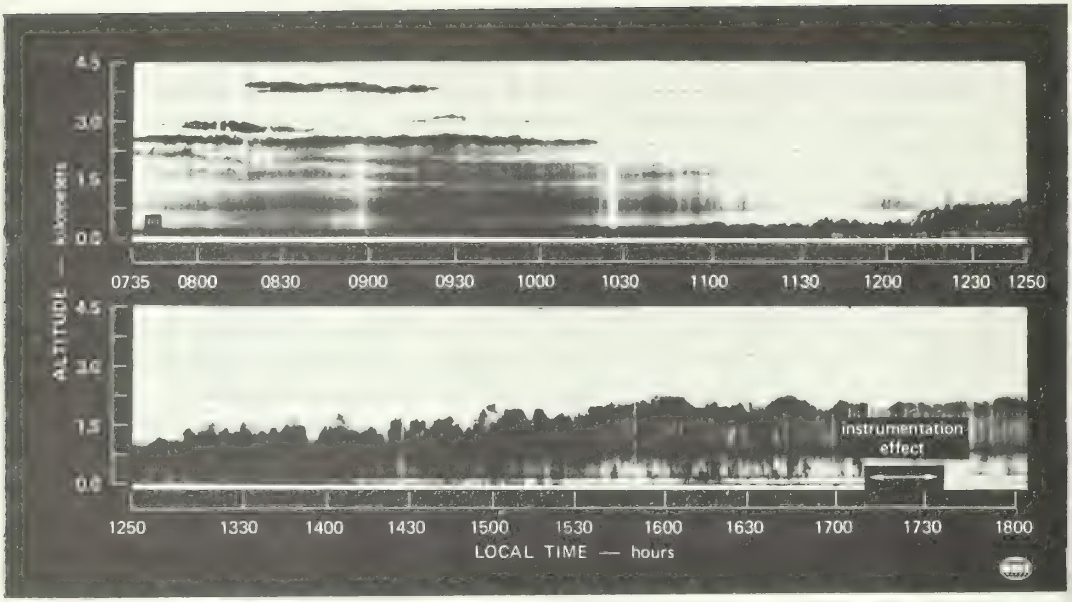


Figure 2.—Height-time cross section of the aerosol structure over St. Louis on 13 August 1971 as observed by Russell *et al. (1974)*.

cloud will be very similar to that over the rural areas.

After sunrise, both in urban and rural areas, any stratus present and the haze particles, will adsorb solar and IR surface radiation and begin to evaporate, improving visibility in the haze levels. These processes at St. Louis are seen clearly in time-height cross sections obtained by our colleagues from Stanford Research Institute with their Lidar (fig. 2, *Russell et al. 1974*).

In rural areas, the surface temperatures will rise rather quickly because the surface inversion limits the depth of initial heating. Dew may be present, in which case the initial temperature rise is delayed by diversion of energy into its evaporation. This in turn will provide additional vapor and tend to cause low-level visibility to decrease, or fog to thicken, for a brief interval in the manner discussed by Pilie *et al. (1975)*.

Within the city after sunrise, skin temperatures begin their climb almost immediately, aided by reduced amounts of dew. This results in a superadiabatic surface layer and initiates thermal convection. Uninhibited by a strong surface inversion, these "thermals" begin to thicken the mixing layer by enfolding air from above it, diluting the smoke and haze that has accumulated during the night. Because of the greater depth of air involved, the surface temperature will rise less rapidly than in the rural areas. As the mixing layer deepens and larger and larger thermals are involved, the top takes on a hummocky character seen so nicely in the Lidar data.

We are assisted in visualizing these dry thermal plumes through the work of Hall *et al. (1975)*, who used three co-volume scanning acoustical sounders tc study dry thermals near Boulder, Colorado. Their data show that individua thermals tended to rise nearly verticall and advect with the wind. They wer more sharply defined on the upwinc edge and less so on the downwind. (Perhaps due to mixing with the environment?) When the mixing layer wa unstable to depths of 300 to 500 m thermal updrafts were 2 mps and mor over a broad mid-height range. Betwee the thermals were downdrafts wit speeds of about one-half that of the updrafts. From double theodolite pilot-balloon data at St. Louis, Ackerman *(1974)*, found similar values for dry vertical currents in the urban boundary layer. This "boiling" of the lower atmosphere is made visible on the Lidar by the presence of large quantities of aerosol particles (note fig. 2, 1130 to 1530 CDT).

After burnoff of the radiation inversion, the rural mixing layer develops in a similar manner but at a slower rate. According to Lidar data at St. Louis, the rural buildup lags that over the city by about 2 hours.

For several hours near mid-day, both urban and rural areas may have superadiabatic surface layers, above which the lapse rate is nearly adiabatic to the top of the mixing layer. In some instances, these superadiabatic layers are surprisingly deep. Using data from an instrumented TV tower in suburban Philadelphia, Davis and Newstein *(1968)* showed superadiabatic layers over 270 m deep on several days of pollution episodes in November 1966 and January 1967; presumably they are even deeper in summer.

On clear days the loss of energy by radiation and diffusion begins to exceed the incoming radiation by mid- to late afternoon, and surface temperatures start to decline. Typically, urban areas lag the rural by an hour or so in the onset of evening cooling. As surface temperatures decline, the source of energy for dry thermals is cut off and vertical mixing decreases.

On days when moisture conditions in the lower part of the boundary layer are adequate, clouds form at the tops of the strongest thermal plumes. When the mixing layer is limited by a strong stable layer, these clouds appear to sit in the top of the mixing layer with only their tops protruding above it (fig. 2). Under more favorable conditions, bulging cumuli may rise through the mixing layer to some elevated stable layer where their growth is arrested. Here they evaporate, leaving the pollutant materials they had ingested through the base as an elevated haze layer.

On days with very large cumulus clouds, the vertical structure of the boundary layer deviates from the orderly progression described above. For now the air motions induced by the cloud, (inflow into updrafts and outflow from downdrafts), begin to dominate the local wind field; evaporation of rain may destroy the heat island. In addition, cloud-shadowed and rain-cooled surfaces are less effective in feeding thermals.

The cool temperatures and high visibility of air that had descended in the downdraft and spread over the surface as a cool air dome are in marked contrast to the hot, hazy conditions before the storm.

In terms of air pollution, a major impact of large convective storms over urban areas is their ability to suck up very large volumes of surface-polluted air, scavenge many of the pollutants for deposition in the rain, and exhaust the remainder at heights up to the tropopause. Large convective storms over urban areas probably contribute appreciably to the Junge sulfate layer in the lower stratosphere.

Before leaving the subject of urban boundary layers, let's consider the results of numerical models of flow over heated islands. Estoque and Bhumralker *(1969)* show that for wind and stability conditions typical of summer at St. Louis, enhanced vertical mixing resulting from the heat island and surface roughness will bring down the higher momentum winds aloft, causing a gradual acceleration of the horizontal winds and slight subsidence over the heated surface. This study also shows that the main convective updraft will be displaced to the downwind edge of the island, very suggestive of the downwind thermal plumes observed by Clarke *(1969)* at Cincinnati. If the models can be applied to conditions over urban areas, subsidence could help explain the moisture deficits observed over St. Louis. Moreover, the downwind displacement of the convection field fits with observed rain excesses on the downwind side of the city.

URBAN EFFECTS UPON CLOUDS AND HAZE

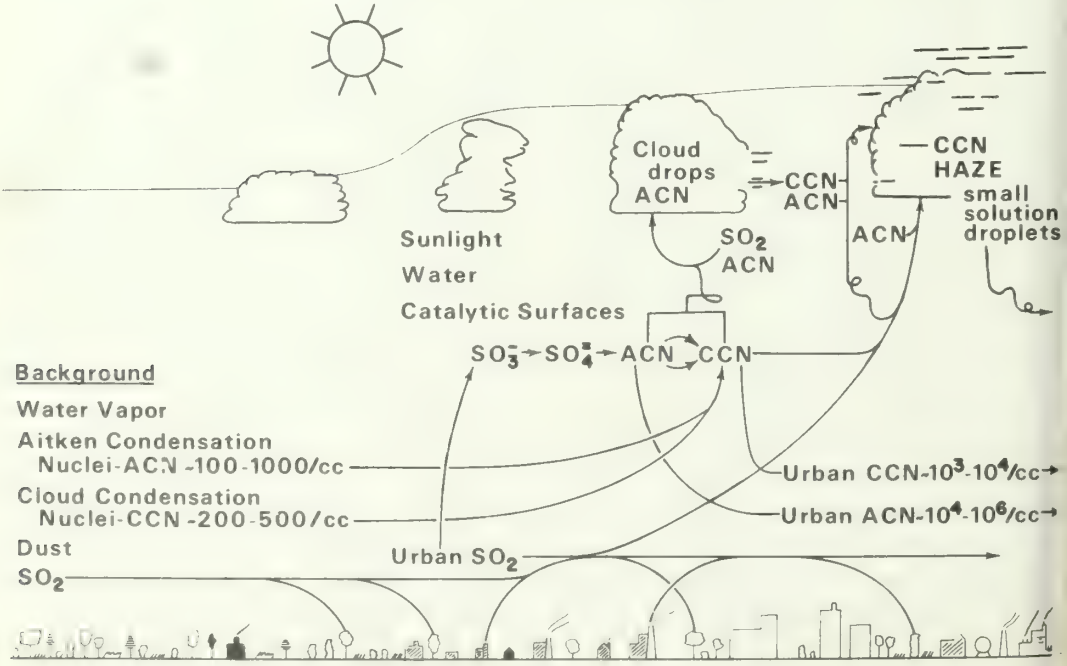
Cities such as St. Louis have a marked effect upon the sizes and concentrations of drops in clouds that ingest the urban air. This effect results from the large numbers of cloud condensation nuclei, CCN, that form within the urban plume. The processes whereby this takes place are outlined in figure 3.

In the pristine atmosphere, far removed from man-made influences, CCN are thought to be submicron particles of ammonium sulfate and sea salt. The sulfate appears to come from biologically derived sulfur gases such as H_2S. In urban atmospheres large quantities of SO_2 are released from fossil fuel combustion and by certain industrial and mining-smelting activities. Much of this sulfur dioxide quickly mixes to the surface where it is absorbed by plants in the first few hours downwind (at least in summer). METROMEX studies give a half-residence time of 4.5 hours for SO_2 released from St. Louis in summer.

Some small fraction of the SO_2 undergoes gas-to-particle conversions to give small particles of sulfuric acid and sulfates. Chemists still are studying the various reactions involved in this process, but there seems to be general agreement that the transformation is most rapid in the presence of sunlight, water, and trace catalytic surfaces. Sulfur dioxide is not the only gas that undergoes conversions to particles. Oxides of nitrogen from automobile exhaust, and other urban effluents, may undergo similar transformations.

Particles formed by gas-to-particle conversions quickly reach sizes of 5×10^{-6} cm and are called Aitken particles or Aitken condensation nuclei (ACN) since they are measured in de-

Figure 3.—Schematic outline of processes responsible for the production of urban nuclei and urban aerosols.


Cloud drops ACN
CCN-
ACN-
CCN
HAZE
small solution droplets
ACN
SO_2 ACN
Sunlight
Water
Catalytic Surfaces
$SO_3^= \rightarrow SO_4^= \rightarrow$ ACN CCN
Background
Water Vapor
Aitken Condensation Nuclei-ACN -100-1000/cc
Cloud Condensation Nuclei-CCN -200-500/cc
Dust
SO_2
Urban SO_2
Urban CCN-10^3-10^4/cc
Urban ACN-10^4-10^6/cc

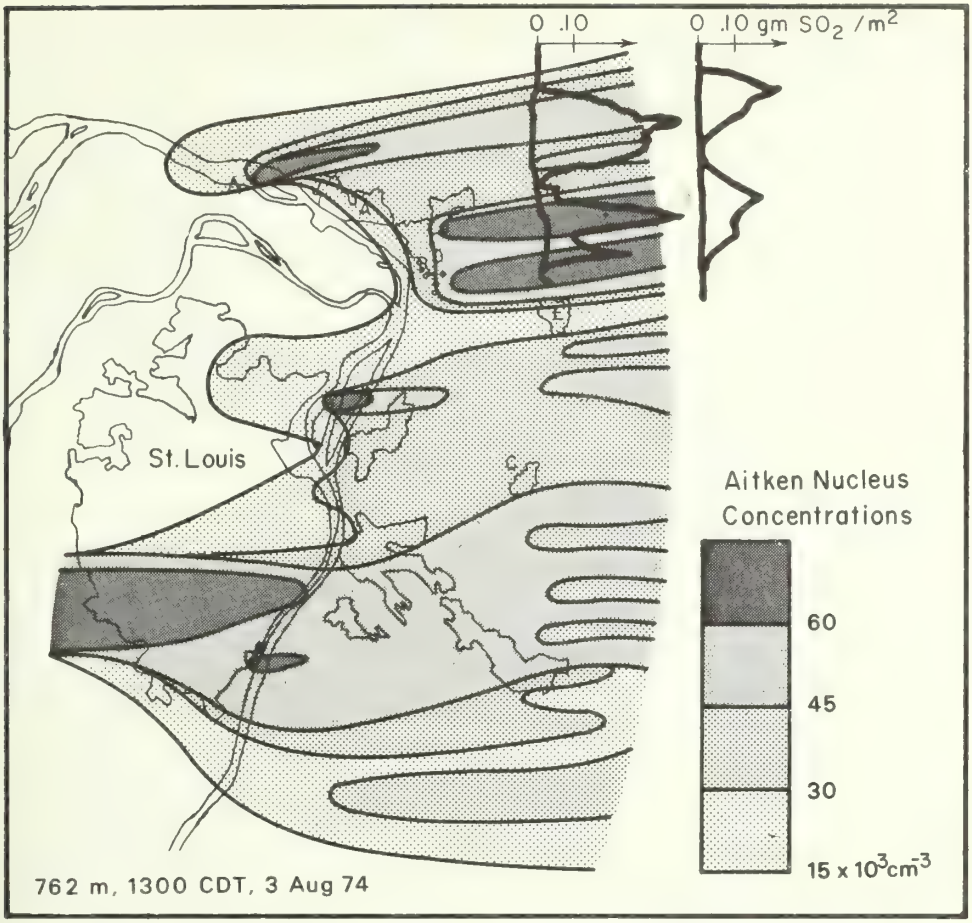


Figure 4.—Aitken nuclei plumes in the urban boundary layer over St. Louis on 3 August 1974, with superimposed plumes of SO_2 as measured by Vaughan *et al.* *(1975)*. The plumes in the upper right show the SO_2 overburden (gm/m^2) above two north-south highways.

vices that cause them to nucleate droplets through supersaturations of several fold.

The concentrations of ACN in clean oceanic air, or over land well above the influences of man's activities, usually are a few hundred cm^{-3}. In the rural boundary layer upwind of St. Louis, summer concentrations are of order 10^3 cm^{-3}. In the urban plume typical values are $10^4 — 10^5$ cm^{-3}. Estimated source strengths of industrial areas are about 1-3 x 10^6 cm^{-2} sec^{-1}.

Aitken particles are too small to directly affect clouds, but they serve as excellent tracers of the urban plume. Using data from our instrumented airplane, we have prepared maps showing ACN plumes for selected clear-sky situations. One such is shown in figure 4. These maps show several Aitken particle plumes arising from industrial areas and large power stations, the large SO_2 emitters in data compiled by EPA. Presumably highway traffic also is a contributor to urban ACN, but our data in St. Louis do not readily resolve such disperse sources. While we were obtaining these data, other scientists were measuring the vertically integrated SO_2 along two highways over which the airplane was flying *(Vaughan et al. 1975)*. Their results are also shown in the upper right quadrant of figure 4. It is clear that the ACN plumes coincide exactly with total SO_2 plumes.

Maps such as these show that the urban plume is a composite of plumes from a number of intense point sources superimposed upon a background from the city. Our data show that in the neutrally buoyant boundary layer, the ACN plumes quickly mix vertically through the depth of the mixing layer and spread horizontally about 10 degrees.

Once formed, Aitken particles continue to grow by further adsorption and oxidation of SO_2, and by coagulation among themselves. New ones keep forming and others are destroyed by coagulation and by interception by haze and cloud particles. The latter process is relatively slow since our measurements inside urban clouds show ACN concentrations exceeding nearby clear air values several fold, at least up to 3 km above cloud base.

The larger the size of a submicron soluble particle, the lower the supersaturation required for it to nucleate and begin growth into a cloud drop. The supersaturation in the bases of many clouds is approximately 0.5 percent (R.H. = 100.5 percent). Particles capable of nucleating in this range of supersaturation are called cloud condensation nuclei (CCN).

Our measurements at St. Louis show that the city is a source for CCN, in both winter and summer, with source strengths of about 10^4 cm^{-2} sec^{-1}. This is equivalent to a volume source of about 0.1 particle sec^{-1} cm^{-3} of urban plume.

One of the key issues as to whether urban CCN can be small sulfate particles concerns the reaction rates of SO_2 conversion into SO_4. Measurements of sulfates in rain over and immediately downwind of St. Louis account for 10 to 20 percent of the SO_2 emission, according to METROMEX measurements. If one assumes that all urban CCN are pure sulfate formed from SO_2, the amount required is substantially less than that observed. Thus it appears that conversion of SO_2 can account for urban CCN, at least in St. Louis.

Ingestion of anthropogenic CCN into the bases of urban clouds results in drop concentrations up to twice that of nearby rural clouds. The sizes of urban cloud drops are correspondingly smaller and the spectra more peaked. A typical example of urban and rural cloud drop spectra is given in figure 5. These observations are in accord with theories relating drop spectra to CCN and updraft speeds *(Mordy 1959, Warner 1969, Fitzgerald 1972)*.

HAZE FORMATION

The mechanism of urban CCN production and nucleation in urban clouds appears to be closely related to one of the most serious of all air-pollution problems—viz., the formation of haze and low visibility during periods of stagnant anticyclonic circulation. During such periods, we find that the minimum visiblity is in the upper part of the mixing layer where there is a scattered to broken layer of shallow cumulus clouds. These clouds evaporate without raining. Between the clouds, and below their bases, are haze particles with modal sizes of several microns, and concentrations of order 1 cm^{-3} of particles up to 15 microns diameter. To be stable at the slight subsaturations involved, these haze particles are most likely small solution drops.

We believe that these particles form by repeated cycling of Aitken particles, SO_2, and CCN through the short-lived clouds (fig. 3). With each nucleation and growth into a droplet, the CCN grow larger. The end product is a large number of large solution particles. Easter and Hobbs *(1974)* discuss the chemistry of this process when operating in shallow wave clouds.

Once created, these solution drops can survive vertical mixing through the depth of the mixed layer and advection over great distances from the SO

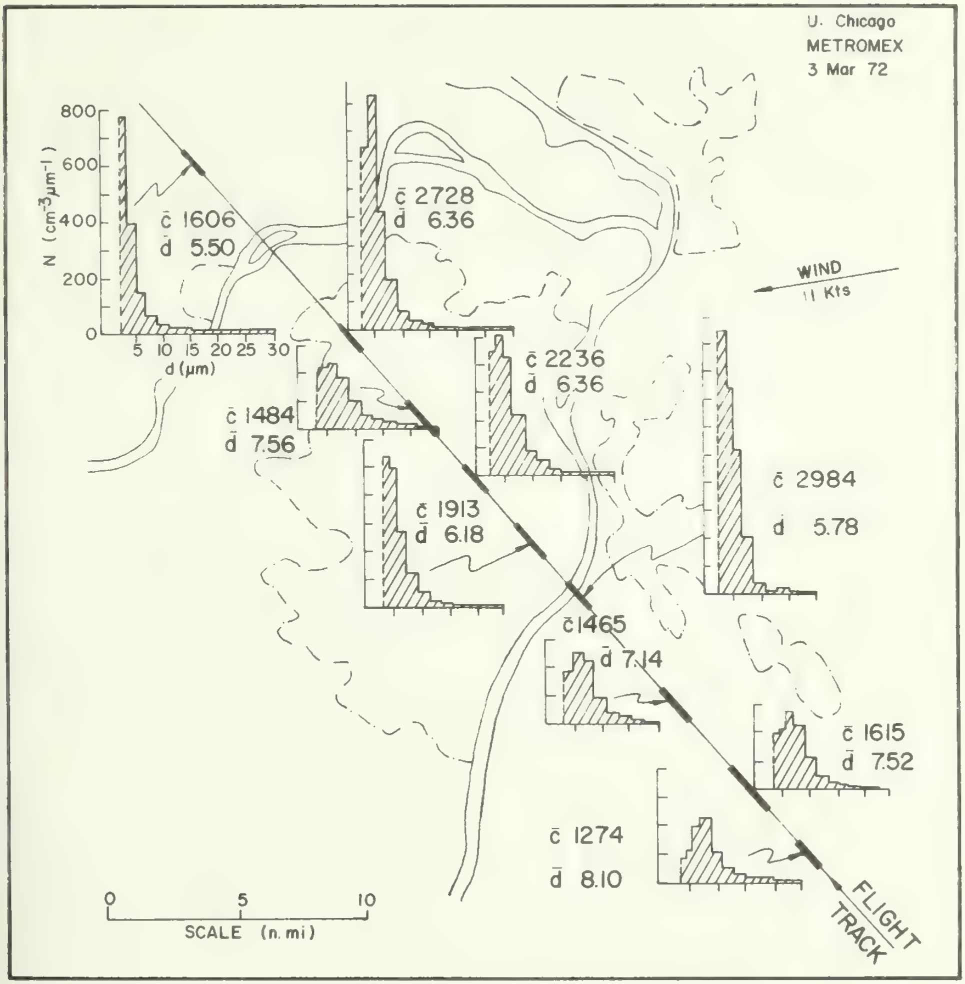


Figure 5.—An example of the effect of urban-CCN on size spectra of drops in clouds. Note the great difference between rural spectra (southeast end of the track) and those downwind of industrial areas and large power stations.

sources. In a sense these drops constitute a disperse cloud which in severe pollution episodes may become thick enough to obscure the sun.

URBAN EFFECTS UPON PRECIPITATION

The meteorology of urban effects upon precipitation is poorly understood compared with that of the urban heat island and the changes in cloud microstructure and visibility resulting from the growth of urban CCN. The issues are at least an order of magnitude more complex, involving interacting cloud dynamical and cloud microphysical processes, both of which are poorly understood and dependent upon conditions of the atmosphere below and around the clouds.

Urban rainfall effects have been studied in two ways: by statistical analysis of precipitation elements observed around cities and by studying the urban-rural difference of cloud dynamical and cloud physics parameters known *a priori* as related to natural precipitation.

Viewed by one who has not been involved in the statistical treatment of observed rain around cities, this approach seems to be troubled by questions of the accuracy and representativeness of historical data and by the difficulty in separating urban effects from local topographic effects. It is well established that low hills (100 to 200 m) can produce local precipitation anomalies comparable to that attributed to urban effects (e.g., *Jones et al. 1974, Bergeron 1968*). Every city is uniquely integrated into its local topography, and there is no statistical device that will unambiguously separate natural topographic effects from those due to man's alteration of the topography by buildings, parking lots, etc. Weekend vs. weekday partitioning of the data and stratifying by wind direction can help reduce, but not eliminate, this problem.

The belief that there is more rain in or near cities than would have occurred at the same location had the city not been built seems to rest mainly upon two facts: (1) local excesses have been observed at a number of (though not all) cities located in a variety of topographic situations; and (2) studies of historical data have shown increasing rain anomalies at some cities as they have grown and become industrialized.

METROMEX has been involved in statistical analyses of rain data, but it also has been deeply involved in measuring physical variables associated with rain at St. Louis in an effort to understand the physics of urban rainfall. According to studies from the Illinois State Water Survey, the largest urban effects at St. Louis are associated with squall lines and squall zones, conditions favorable for natural development of large clouds and moderate to heavy rain. Thus we are faced with the task of working with large clouds whose mere size and complexity make direct observations difficult.

A number of hypotheses have been advanced for physical mechanisms whereby cities might induce local rain excesses. These tend to divide into two groups: those stressing dynamical effects arising from the heat island and surface roughness, and those involving microphysical effects associated with urban derived nuclei, aerosol particles, etc. In either case, one assumes that the urban effect operates by altering natural precipitation mechanisms in some manner.

There are two mechanisms of natural precipitation *(Byers 1965)*. The first recognized and best known is one involving ice particles growing by vapor diffusion in a supercooled cloud; i.e., a cloud of liquid droplets which have cooled below 0°C without freezing. Ice particles are initiated by ice-forming nuclei (IFN). In general, IFN are not the same particles as CCN.

Although data are conflicting, so far it appears that St. Louis is not a significant source of IFN. In fact, it may act to poison natural IFN, especially in the winter months.

The second mechanism of natural rain formation involves collision and coalescence between cloud drops. Many collisions are required because a single rain drop has the mass of about one million cloud drops. Initiation of this mechanism is favored by a broad spectrum of cloud drops such that drops larger than about 40 microns diameter can overtake and coalesce with smaller ones. This mechanism does not require ice particles and can operate equally effectively in clouds either warmer or colder than freezing.

It has been known for some time that coalescence is the dominant mechanism for initial development of rain in cumulus clouds in the Midwest in summer.

Theory says that the narrow drop spectra in urban clouds should delay initiation of the coalescence mechanism. But in fact, the RHI radar shows that coalescence is speeded up, not delayed in summer clouds over St. Louis. It appears that these clouds also develop a few very large cloud drops, too large to relate to the CCN spectra as usually measured. These drops appear as a "large drop tail" on spectra measured in clouds downwind of the city. We presume that these large drops are associated with particulate pollution from the city.

When developing precipitation in a cloud becomes intense enough to be detected by radar we have what is called a radar "First Echo" (FE). In the St. Louis study we find that FE's are warmer than 0°C, hence are coalescence induced. Also, on average, urban FE are slightly lower and warmer than those of rural areas.

The Greenville 3-cm radar shows that the frequency of formation of FE is not uniform over the radar area, with a region of maximum occurring over and downwind of St. Louis.

At the time cumulus clouds produce 3-cm FE's, they have tops barely reaching the freezing level. Unless these clouds continue to grow, the rain they produce will be rather modest.

Let's turn to some of the Illinois State Water Survey measurements of summer rain at St. Louis. They show that the rain pattern for the first three summers of METROMEX was a north-south ridge of rain excesses about 10 miles east of the Mississippi River, and a trough of low rain amounts across the western suburbs. The greatest rain totals were around Edwardsville, Illinois, about 18 miles northeast of the famous St. Louis riverfront Arch. The average rain amount in the ridge is about 1.36 that of the trough.

Over 60 percent of the rain in the Edwardsville area occurred in storms depositing an inch or more. In addition, Edwardsville had substantially more thunderstorms and hail than were observed west of the Mississippi River. Obviously the rain excess at Edwardsville came from clouds much larger than those producing FE's.

When rain periods were stratified by pre-storm wind direction, the downwind quadrant had the larger amounts of rain.

The fraction of each station's total rain that fell during the hours of strongest convection, 1500-1800 CDT, shows a strong maximum centered directly over the city.

Time and space does not permit enumerating the many other observations about clouds and rain which are available on METROMEX. These may be obtained from the Project Principal Investigators.

The most thoroughly developed hypothesis, thus far, to explain the excess in summer rain east of St. Louis, is that of Boatman and Auer *(1974)*. Measurements made by the University of Wyoming group showed that some thunderstorms moving into the city picked up drier and warmer urban air (lower θ_e), which caused the updraft to weaken. University of Chicago radar showed decreases in the heights of the echo tops shortly thereafter. Boatman and Auer argue that the decreasing strength of the updrafts would accelerate the release of suspended precipitation.

This hypothesis is logical and fits observations. It may indeed account for some of the rain excesses over the city. However, it is hard to see how it relates to the observation of increased thunderstorms and hail east of the city since these storms would presumably be declining in intensity as they cross the city.

A second hypothesis that seems reasonable but is less well investigated says that the low-level instability associated with the heat island, plus any action of the city to focus and localize the release of regional instability, might be sufficient to allow the development of large clouds in marginal situations. For example, it has been observed that radar echoes near St. Louis have a bimodal top-height distribution. Large numbers of echoes have tops around the freezing level as a result of mid-level stability on convective days. If the additional buoyancy at cloud base permits some of these clouds to penetrate the stable layer and reach glaciation levels of −10 to −20°C, the heat of glaciation may then provide significantly additional growth, and more rain. It may also be that glaciation is accelerated in urban clouds through microphysical processes associated with urban derived nuclei; however, this possibility has not been demonstrated.

At this time, and stressing again that Project METROMEX is still in progress, it seems to me most likely that any urban effects upon rainfall are associated with cloud dynamical effects associated with the heat island and surface roughness. Cloud microphysical effects, so obviously important in altering cloud-base microstructure and in the development of haze, are probably of less importance in explaining rain anomalies unless there are feedback processes that we have not yet explored.

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Mesoscale Features of Urban Rainfall Enhancement

by F. A. HUFF, *Illinois State Water Survey, Urbana, Ill. 61801.*

ABSTRACT. Analyses of data from the first 4 years of a 5-year research project at St. Louis indicate a substantial enhancement of summer rainfall downwind of the urban-industrial complex. This anomaly appears to be caused primarily by the intensification of naturally occurring storm systems through the addition of heat and raindrop nuclei from the urban area. Most of the enhancement is associated with organized storm systems and is most pronounced during and after the period of maximum diurnal heating.

SINCE 1971, AN EXTENSIVE field and analysis program (METROMEX) has been under way in the St. Louis region to investigate the causes and effects of urban enhancement of precipitation in and downwind of large urban-industrial complexes *(Changnon et al. 1971)*. Huff and Changnon *(1972)*, in a study of eight major cities in the United States, found that the urban environment tends to enhance total precipitation, heavy rainstorms, and severe weather (hail, thunderstorms) in the vicinity.

The St. Louis program involves various types of surface and low-level atmospheric measurements of meteorological parameters. However, this paper is concerned only with findings for the summers of 1971-74 that have been obtained from analyses of data from a dense network of 225 recording rain gages in a circular area of 5,200 km^2 (fig. 1) and a 10-cm PPI radar (FPS-18). These two data sources have provided much information on the differential time and space characteristics of summer precipitation exposed to (1) the urban environment, (2) regional topographical influences, and (3) flat rural areas that serve as a control in evaluating urban and topographical effects on the regional rainfall distribution. Summer is emphasized because the earlier climatic studies *(Huff and Changnon 1972)* showed that the urban effect is most pronounced at that time in the Midwest.

In the METROMEX analyses, four potential sources of localized weather effects were evaluated: the major urban-industrial area of St. Louis, a major industrial area located 10 to 15 km north of St. Louis at Alton-Wood River, and two orographic features (fig. 1). The first of these topographic features is the Ozark Hills, which begin a few kilometers southwest of St. Louis, and the second is the bottomlands of the Missouri River, northwest of St. Louis and west of Alton-Wood River. The roughness of the hills can accelerate both the development and intensification of convective clouds, and the bottomlands are a heat-moisture source conducive to development of convective clouds.

SUMMER RAINFALL PATTERN

In the Edwardsville area the tota summer rainfall for 1971-74 (fig. 1) indicates a peak that is frequently downwind of both urban-industrial areas since westerly winds prevail. The Edwardsville high (120 cm) represents 30 percent positive deviation from th network mean of 91.3 cm, or more tha two standard deviations above the mea The location of this peak and its larg departure from the network mean ar considered strong supporting eviden of an urban enhancement of preci itation. The lightest rainfall in th

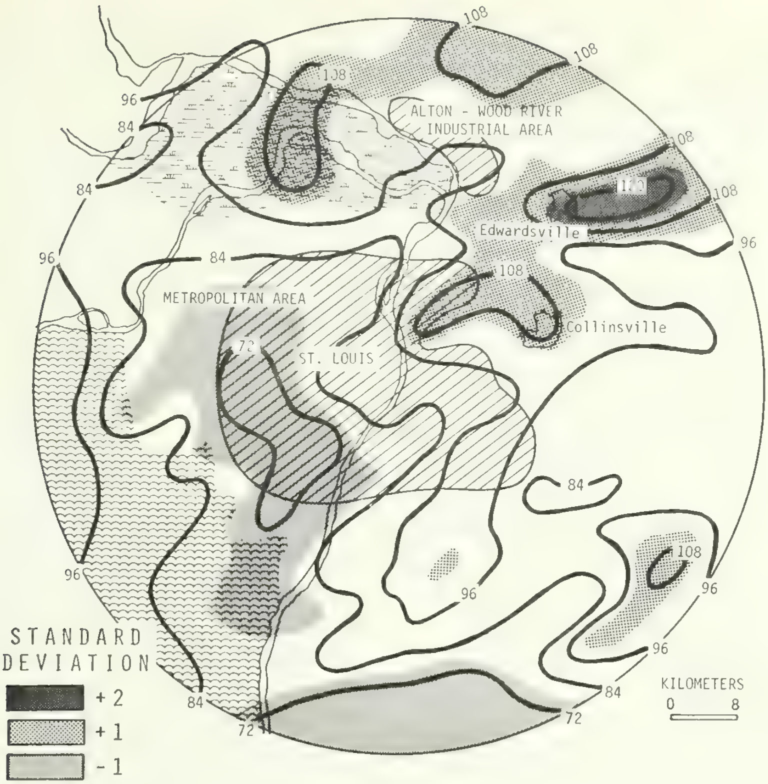


Figure 1.—Total summer rainfall, 1971-74.

four-summer period occurred west and southwest of the major industrial area, which is located along the east of the river. The low region is usually upwind of the industrial region. Thus, the four-summer pattern (fig. 1) shows highs in regions most frequently downwind of the major urban-industrial areas (northeast, east, and southeast of the river) and lows in areas upwind of the urban-industrial complexes.

SYNOPTIC WEATHER RELATIONS

An important consideration in evaluating the causes of urban rain enhancement is the distribution of the precipitation by synopic weather types. In the METROMEX research, efforts have been made to determine what weather processes are active in all rain periods, with special emphasis on the early stages of each rain period, when the urban heat island should exert its maximum effect. In so doing, storms have been classified into five basic synoptic types *(Vogel and Huff 1975)*. These include fronts (cold, warm, stationary), squall lines or squall areas, prefrontal and postfrontal rains, low-pressure center passages, and nonfrontal air-mass storms.

Results to date indicate that more than 75 percent of the summer rainfall in the St. Louis region is associated with organized squall lines and squall areas. These and cold fronts have accounted for nearly 90 percent of the total rainfall on the rain-gage network. Although air-mass storms have accounted for more than one-third of the summer storm occurrences, they produced less than 3 percent of the total network rainfall in 1971-73. This has led to the tentative conclusion that the more active and intense the synoptic situation, the greater are the chances that the city will effectively enhance the precipitation. The air-mass storms, which are unorganized, spatially scattered and usually short-lived, have contributed very little to the rainfall highs easterly of the urban-industrial complexes (fig. 1.)

WIND-RAIN RELATIONSHIPS

Another useful analysis in evaluating the urban effect is to determine the association between surface or low-level winds before rainstorms and the pattern of the resulting rainfall. Both storm movement and the ingestion of heat and particulates (source of rain drops nuclei) into storm systems are related to the low-level wind field. Therefore surface winds have been grouped according to the quadrant from which they blow and averaged for 1 to 3 hours before rainfall, depending upon wind speed. With an active urban enhancement mechanism, the rainfall would be expected to maximize in the quadrant downwind of the city with a given wind movement.

Results to date indicate that, in general, the expected distribution occurs. For example, in 1973 (table 1) the above hypothesis held for all wind movements. That is, with winds blowing from the northeast quadrant (0°-89°) the maximum rainfall with these surface winds (1.40 cm) was in the southwest quadrant. Similarly, the heaviest seasonal rainfall with southeast winds was in the northwest quadrant (15.00 cm), the maximum with southwest winds in the northeast quadrant, and the peak with northwest winds in the southeast quadrant. That is, in each case the highest percentage in each quadrant occurred when the prevailing wind prior to rainfall was blowing across the urban-industrial area. The wind-rainfall relations provide additional evidence of the reality of the observed tendency for the urban environment to enhance the naturally-occurring rainfall downwind of the city.

DIURNAL DISTRIBUTION OF THE URBAN EFFECT

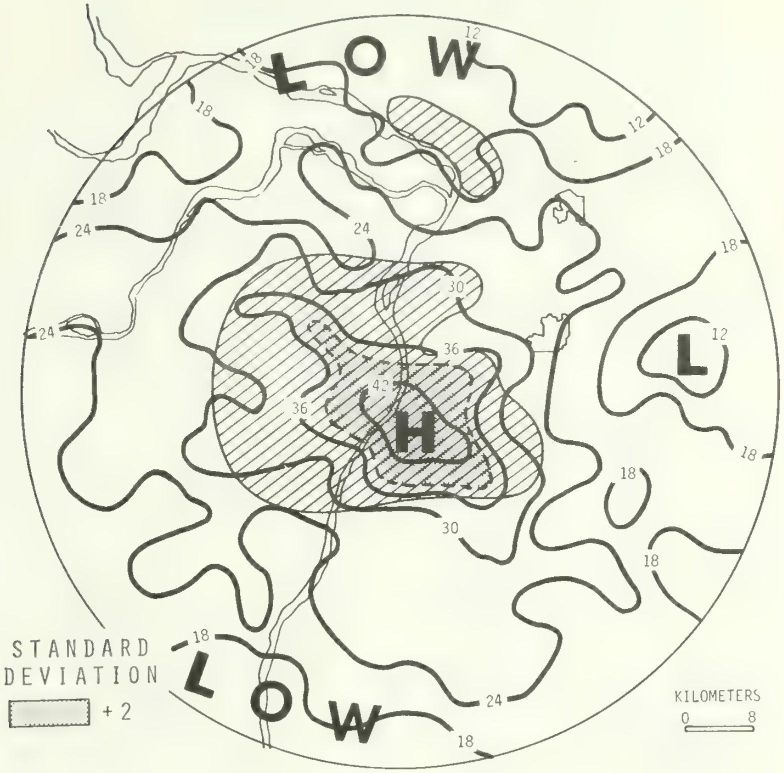
It was hypothesized that the urban effect would maximize diurnally during and immediately after the period of maximum solar heating. At that time, the urban heat discharge combined with the solar heating would tend to produce maximum destabilization in the lower layers of the atmosphere. Then convective growth or development would be favored by the increased thermodynamic instability and/or transferal of raindrop nuclei from stack discharges to cloud base, where they could stimulate the cloud-precipitation processes.

Analyses showed that rainfall tende to maximize over the immediate urba area (fig. 2) in the late afternoon. Fro 1500 to 1800 CDT, several rain gages i the southeastern part of St. Louis recorded more than 40 percent of thei total rainfall for the three-summe period 1971-73. A considerable portio of the urban area (fig. 2) had percentages that exceeded two standard deviations above the network mean of 2

Table 1.—Relation between prevailing surface wind direction before start of rain and network rainfall during summer 1973

Prevailing wind direction	Mean rainfall (cm) for given network quadrant			
	NE	SE	SW	NW
N-E	0.15	0.51	1.40	0.69
E-S	12.20	12.97	12.50	15.00
S-W	11.58	10.00	3.08	2.47
W-N	.25	1.02	.25	.15

Figure 2.—Rainfall pattern for 1500-1800 CDT, 1971-73.



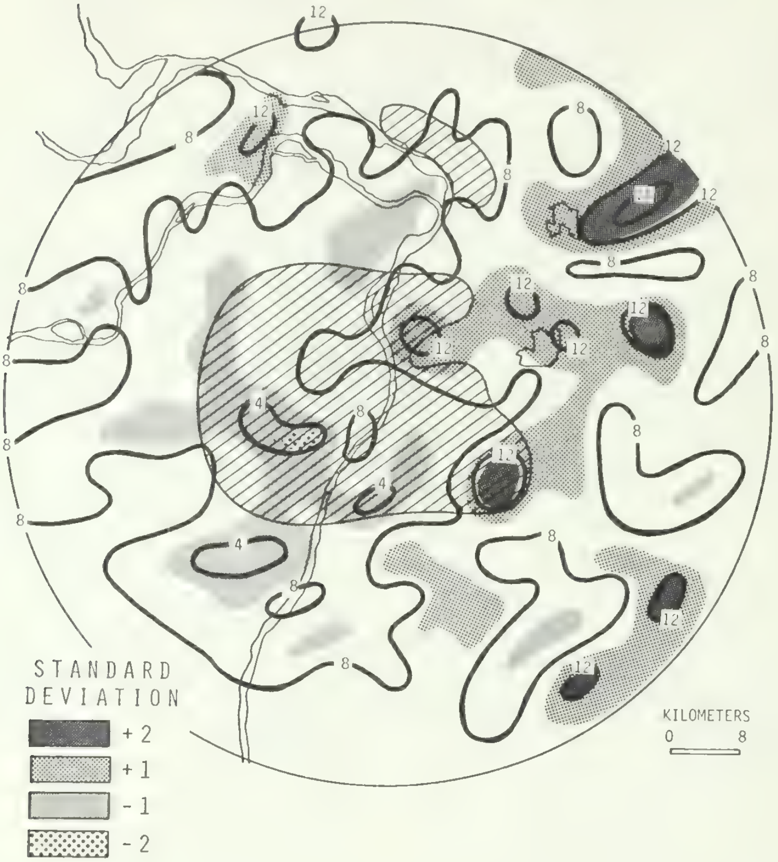
percent of the total rainfall for the three summers. During the following three hours, 1800-2100, the high in the diurnal pattern shifted eastward, as would be expected with raincell initiations in the urban area leading to raincell mergers and intensification of rainfall easterly of the urban-industrial areas. The later high was centered approximately 20 km east of the center at 1500-1800 (fig. 2) and had amounts exceeding two standard deviations above the network mean. Thus the diurnal patterns provide further evidence of an urban-induced enhancement of the natural rainfall downwind of the urban-industrial area.

URBAN EFFECTS ON HEAVY RAINFALL

Another finding from the eight-city climatic study *(Huff and Changnon 1972)* was that the urban effect was most active on days when atmospheric conditions were favorable for storm development from natural processes, and this resulted in a substantial increase in the number of heavy rainstorms downwind of large urban-industrial areas. The earlier finding has been supported by the METROMEX studies, in which the frequency of storm rainfalls of 25-mm or more and their contribution to the total seasonal rainfall have been determined. These storms are of an intensity to be of importance to the hydrologist concerned with the design and operation of urban storm and sanitary sewer systems.

Analyses of the frequency of 25-mm rainfalls at each rain gage during the four summers, 1971-1974, showed a maximum northeast of St. Louis in the Edwardsville area (fig. 3) where the total seasonal rainfall was highest (fig. 1). The low region of heavy rain occurrences was west and southwest of the

Figure 3.—Frequency of 25-mm storm rainfalls, 1971-74.



river (fig. 3) in the same region as the four-season rainfall low. The maxima of 14 to 16 occurrences in the Edwardsville high (fig. 3) were more than two standard deviations above the network mean of eight storms. Rainfall in these storms accounted for over 50 percent of the total rainfall in the Edwardsville high for the 1971-1974 summers; this emphasizes the importance of the heavy storms in defining the general rainfall pattern and controlling the location of high and low centers in the network pattern.

Our studies to date indicate that the maximization of heavy rainstorms in the Edwardsville region occurs from the enhancement of natural storm systems, particularly squall and cold-front systems, as they move across the St. Louis or Alton-Wood River areas. The urban environment acts to intensify existin raincells and to initiate new raincell within ongoing storm systems. Thi results frequently in maximum rain outputs near Edwardsville, which lies a fe km east-southeast of Alton-Wood Rive and northeast of St. Louis.

A number of case studies have show that quasistationary mesosystems, maintained by mergers with urban relate convective cells, are a common cause o severe rainstorms of hydrologic significance in the urban region *(Vogel an Huff 1975).* Mergers are frequently associated with storm intensification, an these are favored in the urban regio where the environment stimulates ne raincell formations and growth of existing convective entities. Other finding from the METROMEX studies sho that raincell initiations are frequent sociated with "hot spots" in the ex- erimental area, and these occur more equently within the urban region than the surrounding rural regions. From rcraft measurements, there are also dications that large amounts of con- ensation nuclei of urban origin are mmonly ingested into cloud systems the vicinity, and this provides another tential mechanism for initiating rain- ll and intensifying ongoing storm stems. In general, analyses to date dicate that excessive heat output from e urban region (a destabilizing force), d raindrop nuclei ingestion from the ban-industrial stack outputs, are prob- ly the major causes of urban rainfall hancement.

RAINCELL ANALYSES

A primary method of evaluating the rban effect in METROMEX studies as been through comparison of urban- fected and rural (non-affected) rain- lls. Only those cells that spent their tire life on the network (complete lls) are used. Comparisons have been ade for various stratifications of the ata, but in this paper I will discuss ly analyses of heavy raincells that are primary concern to the urban hydro- gist. For this purpose, the 300 cells ith the heaviest mean rainfall were parated from the 2,688 complete cells mpled in the 1971-73 summers. This cluded all cells with mean rainfall of mm or more. A raincell is defined as a sed isohyetal entity within the overall veloping isohyet of a rainstorm system; that is, it defines an isolated area of significantly greater intensity than the system enveloping isohyet, and must last more than 5 minutes to qualify as a cell *(Schickedanz 1972)*.

Comparison of the water yield (rainfall volume) from the heavy cells with all 2,688 cells showed that the 300 cells (11 percent of total) accounted for 63 percent of the total water yield. Similarly, the heaviest 100 cells (4 percent of total) produced 40 percent of the water output by all 2,688 cells, and the 50 heaviest cells (2 percent) accounted for 28 percent of the 2,688-cell rainfall. The weight that these cells exert in determining the network rainfall pattern and the magnitude of any urban effect is obvious from the above calculations.

A cell was considered to be potentially urban-effected if it developed over or passed through either of the two major urban-industrial areas. Of the 300 heavy cells, 118 were classified as urban-effected and 134 were included in the rural (no-effect) group. The remainder fell into the topographic-effected group. A comparison of percentage differences between the water yield of these two groups showed that the urban cells had a median output of 1.05 x 10^6m^3, which was 55 percent greater than the rural cell median (table 2). The difference was 97 percent or more for the heaviest 5 percent of the cells and was 29 percent or greater when 95 percent were included. The comparison of water outputs associated with the urban and rural cells (table 2) provides further evidence

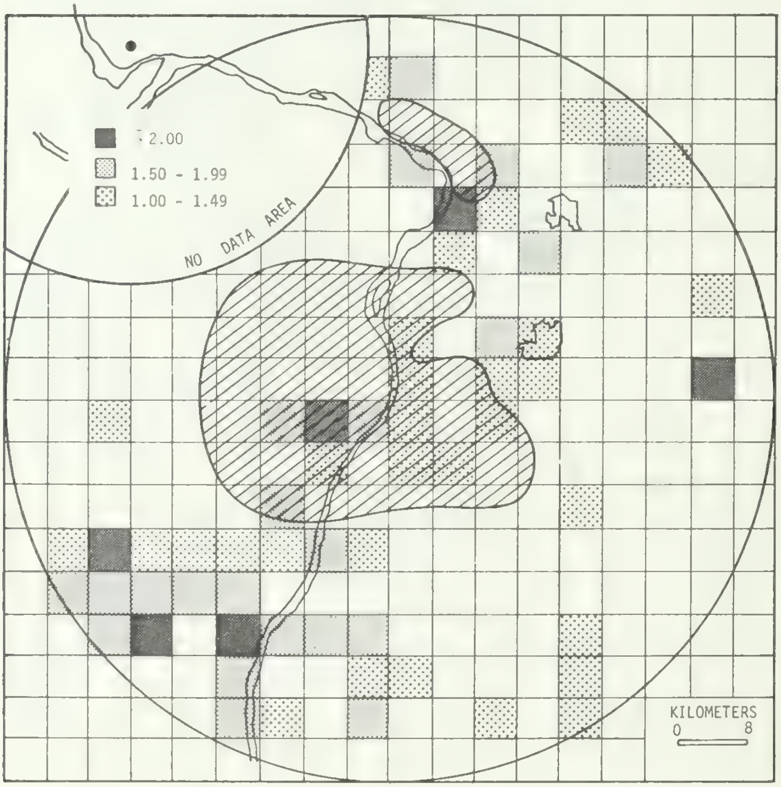
Table 2.—Comparison of water yield between urban-effect (U) and no-effect (C) raincells among 300 heaviest cells in 1971-73

Cumulative percentage of raincells	Urban-effect volume (m^3)	U - C (m^3)	Percent difference
5	4.75 x 10^6	2.32 x 10^6	97
25	1.99 x 10^6	8.43 x 10^5	73
50	1.05 x 10^6	3.70 x 10^5	55
75	5.83 x 10^5	1.82 x 10^5	45
95	2.47 x 10^5	5.56 x 10^4	29

Table 3.—Comparison of percentage difference between urban-effect and no-effect rainfall parameters in 1971-1973 heavy raincells

Cumulative percentage of raincells	Percentage difference equalled or exceeded			
	Mean rainfall	Area	Path length	Duration
5	20	72	72	42
25	11	51	56	20
50	11	35	45	10
75	10	32	29	14
95	10	25	17	11

Figure 4.—Number of radar echo initiations per 25 mm of rainfall.



of the urban effect and its observed tendency to increase with increasing rainfall yield from natural causes. Statistical tests (u-test and t-test) showed the urban-rural differences to be significant at the 1 percent probability level.

Comparison of urban-rural raincell differences for various rainfall parameters showed the maximum difference associated with rainfall volume that tegrates the effects of cell area, durat intensity, and path length. Howe other parameters did show larger va for the urban cells (table 3). For ample, median percentage differe were 45, 35, 11, and 10 percent res tively for cell path length, area, m rainfall, and duration (table 3) pared with 55 percent for rainfall me (table 2). This consistency of ositive differences between cell parameters adds to proof of the urban effect.

RADAR MEASUREMENTS OF URBAN EFFECT

Analyses were made of radar echo bservations from 27 storms sampled vith the 10-cm FPS-18 radar in 1972-74. Major emphasis was placed on preferred areas of echo initiation and echo nergers in the METROMEX network. nitiation counts were based upon the umber per 23 km² (9 mi²) and merger ounts on the frequency per 92 km² (36 ni²). Results of these analyses indicated strong trend for echo initiations (rain ntities) to occur most frequently in and lownwind of the urban-industrial areas nd in the Ozark foothills (fig. 4). The nost frequent region of occurrence was n the vicinity of oil refineries at Wood River, where the normalized frequency (number/25-mm of rainfall) was 50 ercent greater than for any other unit rea in the network.

Raincell and radar echo mergers are frequently associated with intensification of ongoing storm rainfall. Therefore the radar data were examined for the distribution of echo mergers in the 27-storm sample. Results showed the most frequent area of mergers near he eastern and southeastern boundaries of the urban area of St. Louis, and a secondary maximum appeared in and downwind of the Ozark Hills, as well as downwind of the urban area. Thus, the radar analyses add support to validation of the urban enhancement mechanism by exhibiting a source of above-normal frequency of raincell development and intensification in the urban-industrial regions. The radar analyses also showed that the foothills are likely a region of topographic effect on convective development and rainstorm enhancement.

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The Urban Moisture Climate

by DOUGLAS L. SISTERSON *and* RICHARD A. DIRKS, *graduate research assistant and professor, Department of Atmospheric Science, University of Wyoming, Laramie, Wyo. Sisterson is now with the Atmospheric Physics Section, Argonne National Laboratory, Argonne, Ill.*

ABSTRACT.—Data collected on 26 July 1974 as a part of project METROMEX in St. Louis show the three-dimensional structure of the urban moisture field. Mesoscale dry regions at the urban surface, corresponding to large residential and light industrial land-use characterization, were responsible for a reduction in specific humidity in the urban mixing layer. Anthropogenic sources and sinks of water vapor were estimated and found to be insignificant for summer daytime mesoscale influences on the atmospheric water balance of the urban area. The effects of reduced moisture in the urban area are directly related to the urban heat island, visibility, fog, precipitation, and human comfort in our cities.

HUMAN LIFE PATTERNS have changed radically in the last century with the increasing migration from rural to urban areas. The increased magnitude of climatic anomalies accompanying urban-industrial expansion are well documented by the urban heat island and are further evident in the effects on visibility, fog, moisture, and precipitation. These factors are important to human comfort, land-use planning, and engineering considerations.

The moisture budget appears to be a key contributor to urban climate anomalies. Seasonal surface-moisture anomalies have been noted in large urban areas. The greatest urban-rural humidity differences are during summer afternoons when the urban dry island is greatest in magnitude. Summer nighttime differences in urban-rural absolute humidity patterns suggest that the city is drier when the nocturnal heat island is strongest. Wintertime studies, however, show that the urban area is more moist than its rural counterpart. Intensification of the urban heat island has been directly related to less absolute moisture *(Wood 1971)* and reduced evaporation *(Myrup 1969)*. A reduction in urban moisture, with a corresponding
reduction in latent heat energy, ma
also account for anomalous precipitatio
patterns *(Terjung et al. 1971; Boatma
1974)*. On the local scale uncertaint
has been expressed whether the overa
water contribution from the city is r
duced compared to rural areas sin
much water vapor is released by co
bustion, industry, and cooling operatio

Project METROMEX (*METRO*po
tan *M*eteorological *EX*periment) w
initiated in 1971 to statistically a
physically evaluate the possible mod
cation of weather and climate by
urban-industrial complex. Recent stud
by the University of Wyoming in Pr
ect METROMEX focused on the pr
lem of urban moisture *(Sisterson 197*
Data were acquired from the inst
mented Wyoming research aircraft a
instrumented meteorological weat
mobiles, along with surface netwo
operated by cooperating groups (Illi
State Water Survey, St. Louis City
County Air Pollution Agencies).

Three aspects of urban moisture w
investigated: (1) relative magnitu
of anthropogenic sources and sinks,
the three-dimensional structure of
moisture field, and (3) evaluation
the moisture budget components.

SOURCES AND SINKS OF MOISTURE

Estimates of automobile and industrial sources of water vapor were compared to potential evaporation calculations. The industries chosen in this study warranted investigation because of their size and location in the St. Louis area. The results of water vapor production rates (gm hr^{-1}) for anthropogenic sources and potential evaporation for the urban area are shown in table 1. Even if only a fraction of the radiation energy is used for evaporation, it is apparent that potential evaporation (for a 30-km by 30-km surface area) is several orders of magnitude greater than anthropogenic moisture sources. However, industrial sources are essentially point sources of water vapor. If the potential evaporation is considerd for an area only 3 km by 3 km, the rate of water vapor production approaches that of the major industrial sources. Thus, during the daylight hours, anthropogenic sources do not appear to be of consequence except on the local scale. At nighttime, when potential evaporation is greatly reduced and mixing is limited, anthropogenic sources are indeed a relevant factor in the urban water balance, so that the urban atmosphere at night may be more moist than the rural atmosphere.

Hygroscopic aerosols, photochemical reactions, and precipitation are major moisture sinks for an urban atmosphere. In this study, cases were chosen on nonprecipitation days, so the precipitation component was neglected. Particulate mass concentrations of 100μgm m^{-3} (0.5μm size) have been reported for a highly polluted day in Los Angeles, California. In the extreme case, all particles are assumed to be hygroscopic salt particles at a relative humidity of 90 percent. For this case, the maximum change in specific humidity in the urban area (30 km by 30 km by 1.5 km) would be only 2.75×10^{-4} gm kgm^{-1}. This amount is insignificant and cannot be detected by moisture measurement.

Investigation of photochemical reactions in the urban atmosphere was limited to the formation of sulfuric acid, the most common and prolific photochemical pollutant. In the extreme case, all sulfur dioxide was assumed to react with water vapor to form sulfuric acid. In all cases, the water vapor necessary to convert all the SO_2 to H_2SO_4 was at least one order of magnitude less than the water vapor emissions from the industry.

Sulfuric acid is also deliquescent at high concentrations. The excess water vapor between industrial source and reaction requirements was used to dilute sulfuric acid concentrations in the industrial plumes. The Labadie power plant plume showed the greatest potential concentrations of sulfuric acid. Only if the environmental relative humidity is greater than 94 percent could sulfuric acid from the Labadie plant absorb ambient water vapor—again assuming

Table 1.—Urban area sources of water vapor

Classification	Source	Water vapor (gm hr^{-1})
Auto	Automobile	2.3×10^{8}
Refineries	Amoco	1.2×10^{8}
	Shell	3.0×10^{8}
Power Plants	Meramec	2.0×10^{7}
	Portage des Sioux	1.9×10^{7}
	Labadie	5.8×10^{7}
Cement	Alfa	2.9×10^{7}
	Missouri Portland	7.6×10^{7}
Steel	Granite City	1.8×10^{8}
Nature	Potential Evaporation	6.7×10^{1}

all SO_2 converted to H_2SO_4. The photochemical reaction of sulfuric dioxide and water vapor is therefore clearly not a significant factor in the extraction of water vapor from the urban atmosphere on the mesoscale, and in general, the deliquescense of sulfuric acid is insignificant.

ST. LOUIS CASE STUDY— 26 JULY 1974

Atmospheric moisture patterns are influenced by advection, turbulent mixing, and local sources and sinks of moisture. In the METROMEX field studies, aircraft transects were chosen so that unique air columns were successively intercepted at two flight levels as they passed over the urban area. The flight pattern thus minimized advection. Horizontal turbulent mixing was found to be insignificant and downward entrainment of dry air into the mixing layer was initially assumed insignificant with the presence of a subsidence inversion.

Because surface data were acquired from fixed stations, the time rate of change of surface moisture measurements included advection. Calculations showed that surface moisture advection on the mesoscale was insignificant. Local advection, however, was not assessable and may be important.

Temperature and moisture comparison between corrected weather mobiles, hygrothermographs, and telemetry stations at locations where data from all three uniquely different sources could be compared, showed consistent results. A similar consistence was observed between aircraft and radiosonde measurements in the free atmosphere. It is important to recognize that the characteristic of the moisture anomalies described in this section were consistent among four independent types of instruments.

Data from 26 July 1974 for 1530 to 1630 CDT are presented to illustrate moisture patterns that have been observed on a number of fair summer days. Low-level winds on this day were northerly with speeds less than 5 m sec^{-1}. Specific humidity and potential temperature patterns are shown for the surface at 1600 CDT (fig. 1). Dry regions exist along the northern, southern, and western edges of St. Louis, corresponding to major residential and light industrial land-use characterizations (fig. 2). Heat islands are apparent north of the city and along the southern edge. Because these analyses are based upon individual stations, local effects influence station readings, and small regions of low moisture and high temperatures are apparent *(Chandler 1967; Kopec 1973)*. Weather mobile data also show as much as 2 gm kgm^{-1} and a 10 variation in moisture and temperature respectively, over distances of 1 km.

Patterns of specific humidity and potential temperature are shown fo 450 m MSL (300 m AGL) in figure 3. A single widespread dry region exist along the southern edge of St. Louis with tongues of dry air extending alon the eastern and western edges of th metropolitan area. A single heat islan is also apparent and corresponds to th dry region. Both humidity and temp erature patterns are reasonably we correlated with those on the surfac The patterns of specific humidity an potential temperature patterns at 900 MSL (fig. 4) correlate well with those 450 m MSL. Both dry regions and hea fields are more widespread at the upp level.

From data acquired at the three leve between 1530 and 1630 CDT, thre dimensional analyses of the moistu fields in the mixing layer were co structed. Isopleth analysis of the speci humidity is shown for 10.2 gm kgm (fig. 5) and 11.8 gm kgm^{-1} (fig. 6). plume-like structure with an hourgla configuration is evident. The drier su face air is apparently mixed vertica through the mixing layer. Measu ments of the wind field convergence a

Figure 1.—Specific humidity (gm kgm^{-1}) and potential temperature (°K) patterns for the surface at 1600 CDT. Heavy dashed lines show weather mobile transects. The shaded region defines urban and suburban areas.

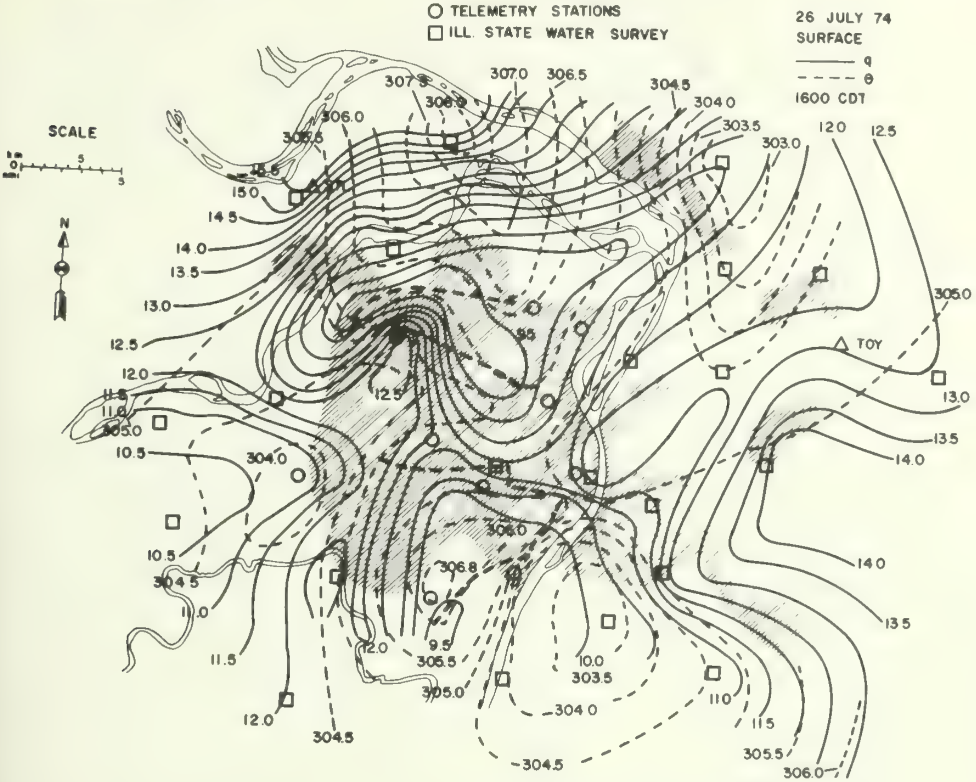


Figure 2.—St. Louis and surrounding area land use characteristics. Roadways and their corresponding route numbers are shown. The solid triangles represent the St. Louis and Troy navigational vortacs.

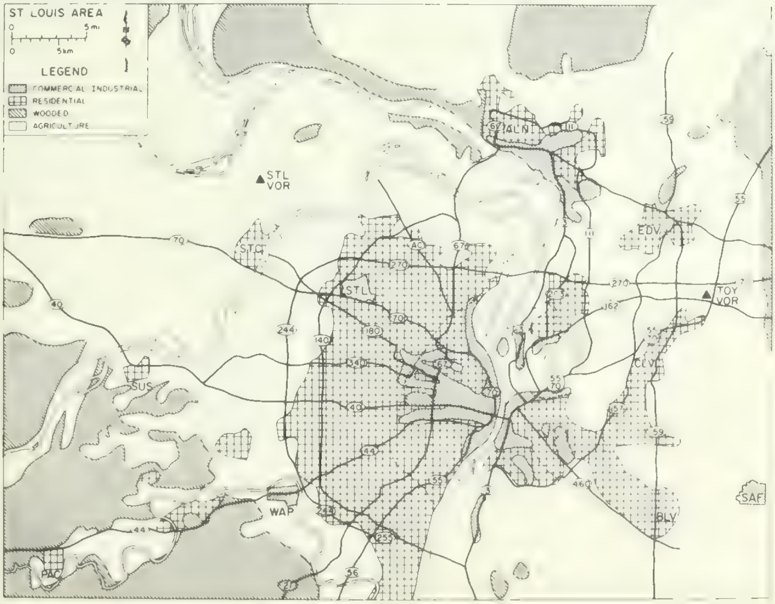


Figure 3.—Specific humidity (gm kgm^{-1}) and potential temperature (°K) patterns at 0.45 km MSL (1530-1630 CDT).

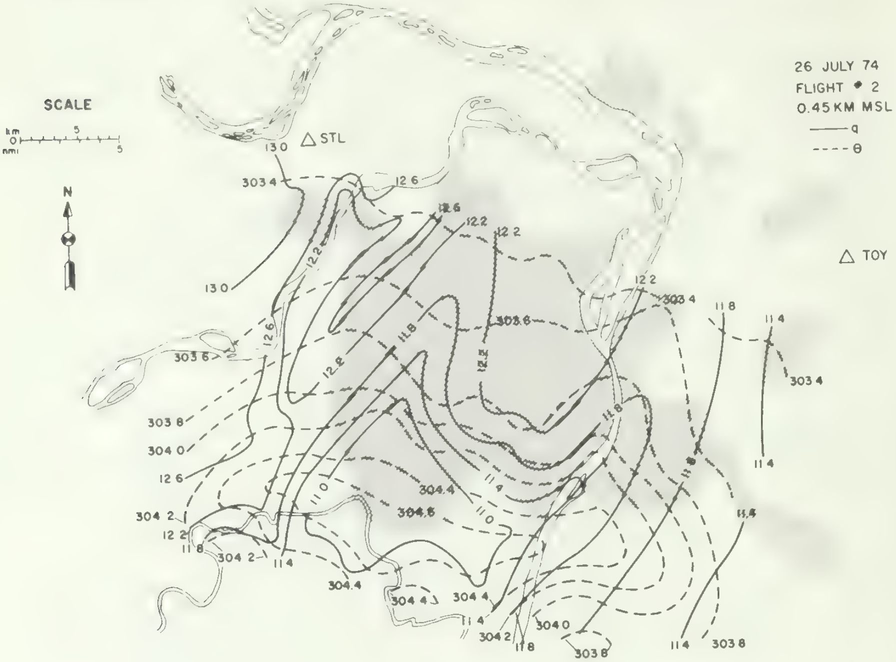


Figure 4.—Specific humidity (gm kgm^{-1}) and potential temperature (°K) patterns at 0.9 km MSL (1530-1630 CDT).

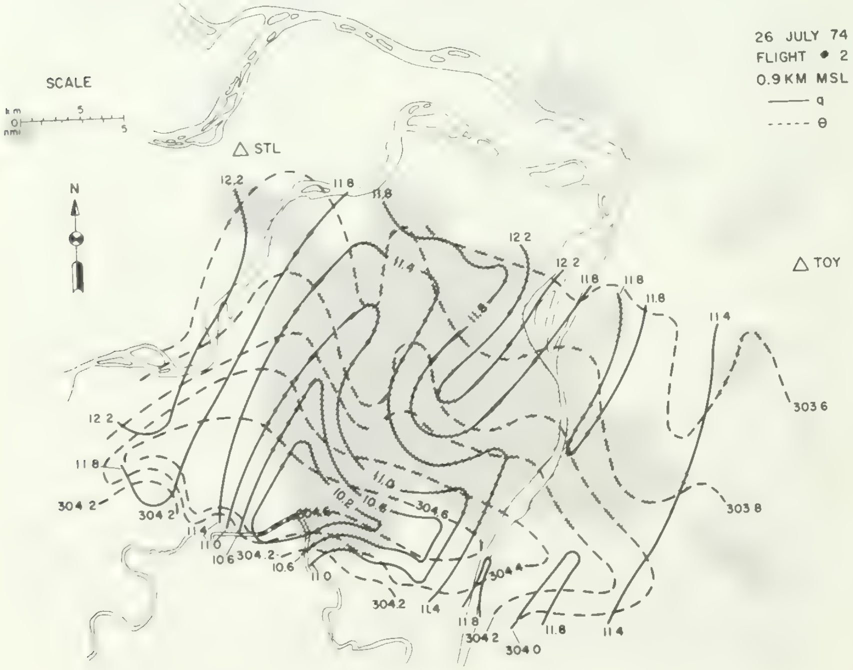


Figure 5.—Three dimensional analysis of the 10.2 gm kgm^{-1} isohume (1530-1630 CDT) for 26 July 1974.

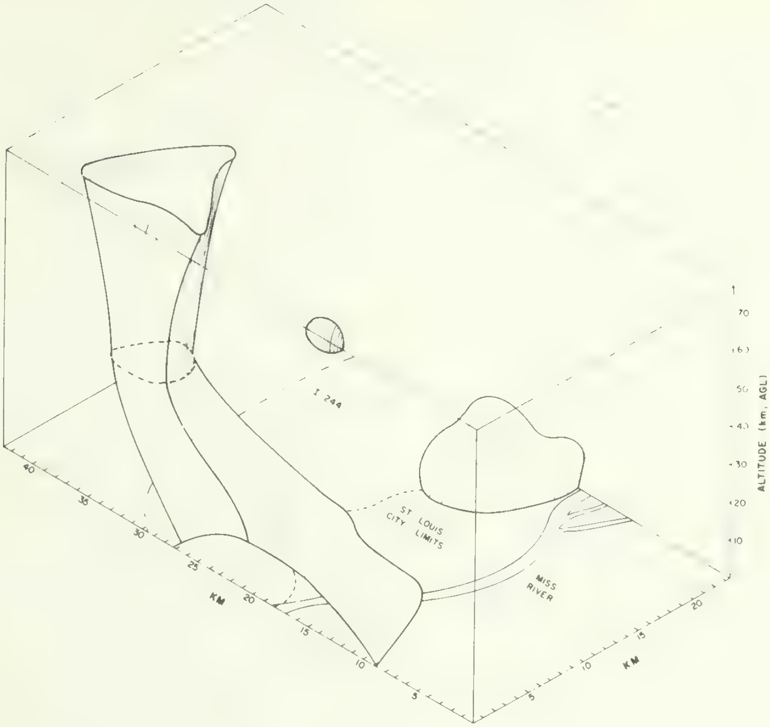


Figure 6.—Three dimensional analysis of the 11.8 gm kgm^{-1} isohume (1530-1630 CDT) for 26 July 1974.

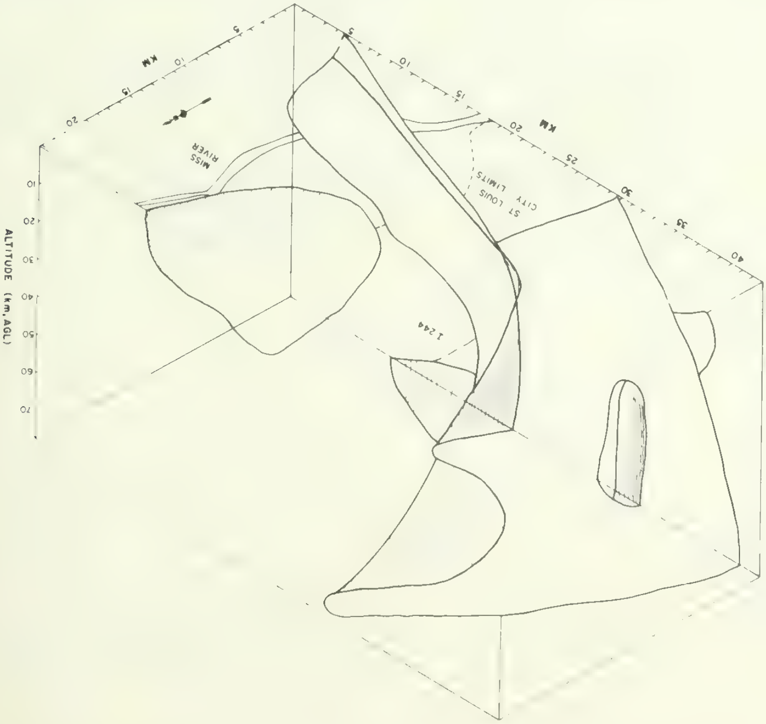


Figure 7.—Upwind aircraft sounding at 1533 CDT.

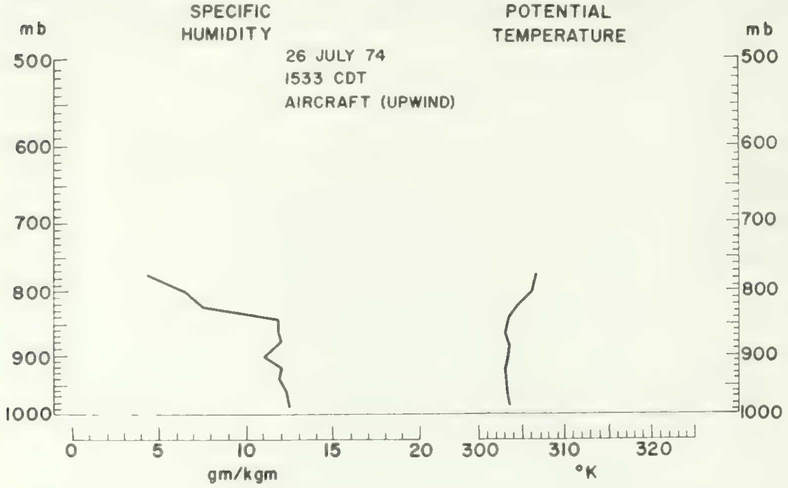


Figure 8.—Tower Grove Park radiosonde sounding at 1500 CDT.

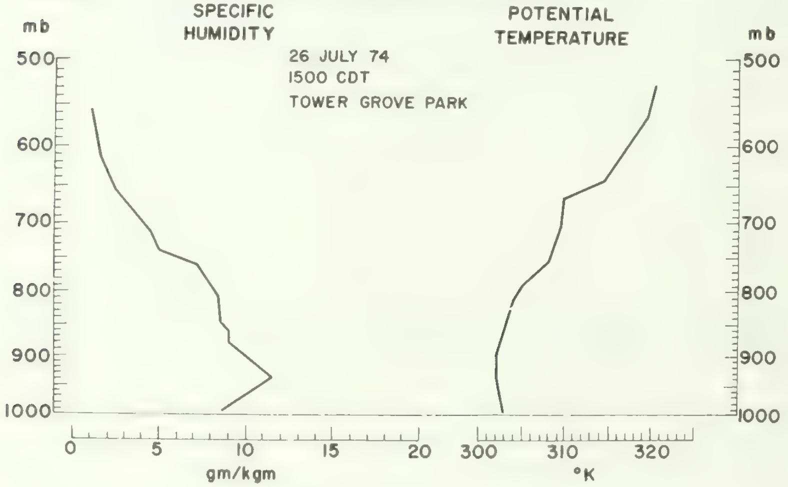
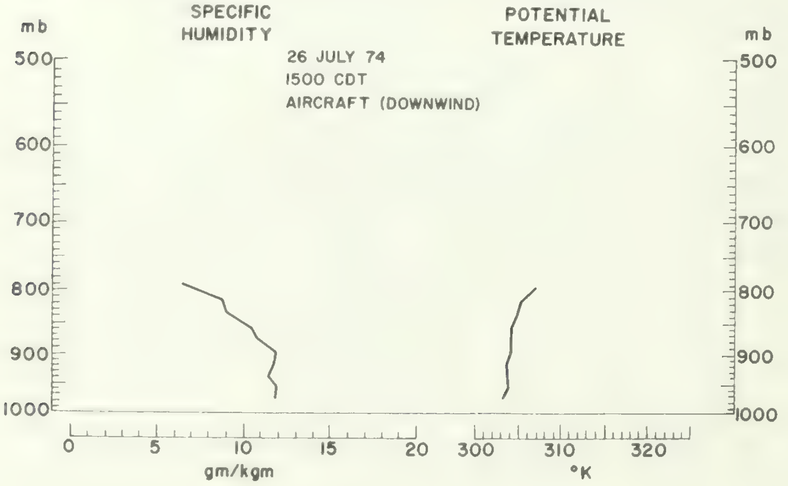


Figure 9.—Downwind aircraft sounding at 1500 CDT.



support the concept of convergence and ascent in the dry regions.

Aircraft and radiosonde soundings were also analyzed for the effects of urban modification on vertical moisture profiles. Aircraft soundings were extrapolated to the surface, using local surface values of humidity and temperature. Likewise, values from an aspirated psychrometer established the surface temperature and humidity for radiosondes. Three soundings (upwind, over, and downwind to St. Louis), taken within a period of 30 minutes, are shown in figures 7 to 9. Particular attention is focused on the lowest 50 mb moisture profile of each sounding. The upwind sounding shows a slight decrease in specific humidity with height. The sounding at Tower Grove Park, (5 km southwest of downtown St. Louis), taken near a large concrete area, shows a large increase of specific humidity with height. The downwind sounding shows only a slight increase of humidity with height. These soundings show that within the lowest 50 mb the urban surface is drier than the air above 950 mb on this day. These features are characteristic of a number of case study days. Hence, as air columns pass over the urban area from a region of high surface humidity (upwind) to a region of lower surface humidity, the mixing of dry air into the columns reverses the low-level humidity gradient and decreases the average specific humidity of the columns.

These soundings also show that the inversion is elevated over the urban area by 600 m. The sharp moisture discontinuity at the base of the inversion of the upwind sounding is not present over the city. There is an apparent eroding of the air beneath the inversion, probably attributable to nonuniform downward entrainment of dry air. This violates the previous assumption of negligible entrainment into the mixing layer. This entrainment term could not be assessed, but it is apparent that downward mixing across the inversion will also dry out the columns.

Overall, the urban-influenced atmosphere is drier than the surrounding rural area. Because there is less moisture potential at the city surface (vegetation, porous soils, etc.), less energy is used for evapotranspiration purposes. The excess energy is then utilized between sensible heat energy and ground stored energy, which generally causes the urban atmosphere to be hotter.

In summary of the 26 July 1974 study, dry regions are found within the St. Louis urban area. These regions of low specific humidity correlate well with impervious surfaces found in the densely populated residential areas and light industrial areas. Although the moisture content of air columns passing over the city may decrease from downward entrainment of dry air from above the mixing layer, reduced evapotranspiration at the surface clearly contributes to a reduction in average specific humidity of the columns. It can be inferred that up to 50 percent of the St. Louis area *(Marotz and Coiner 1973)* is represented by modified surfaces. Thus the urban surface environment is drier due to reduced evapotranspiration from widespread impervious surfaces.

RELEVANCE TO URBAN-DWELLERS

From energy budget considerations, nearly equal amounts of radiation are available at both urban and rural surfaces *(Maisel 1971, Rouse et al. 1973)*; however, less radiation is used as latent heat energy, so that sensible heat energy and ground stored energy must be greater in the urban area. Loose soil and plant material characteristically are very poor heat conductors and have a low heat capacity. Hence all heat transactions take place in a thin surface layer in most rural areas. In contrast, urban areas have massive surfaces of stone, brick, concrete and asphalt. These have better heat conductivity than soils and therefore may be warmed to appreciable depth by incoming solar radiation. Nocturnally the stored heat is gradually released, which keeps the city surfaces warmer than surrounding grassland or trees. In addition, the heated vertical surfaces of buildings radiate toward each other and do not lose heat by radiation toward the sky as a horizontal surface in the open country would *(Landsberg and Maisel 1972)*.

The increase in sensible heat energy (the heat island) is a well-documented phenomenon in urban areas. High environmental temperatures affect health. Prolonged exposure to high temperatures associated with summer heat waves can result in death either as a primary cause or as a contributing factor in heart disease, strokes, and pulmonary disorders. There is evidence to suggest that a large percentage of heat-related deaths may be of man's own design by climate modification through urbanization. Clarke and Bach *(1971)* showed a relationship between average daily temperature and deaths attributed primarily to heat during the July 1966 St. Louis heat wave, in which 500 deaths occurred in East St. Louis, Illinois. Although no heat deaths occurred at an average temperature of 31.7C, deaths increased markedly with every one-degree increase in temperature above 32.2C (assumed the critical level). A rise of the average daily temperature of only 0.6C above 32.2C resulted in 11 heat deaths. Seventy-three heat deaths occurred when the average daily temperature was 35C. This 2.8C increment of average daily temperature is about the same as the average temperature difference between the urban and suburban environments, based on the afternoon and evening temperatures obtained in Clarke and Bach's study.

Other effects of the urban moisture climate may also contribute to man's discomfort in his atmospheric environment. The reduced moisture content of urban-influenced air may locally deprive storms of latent heat energy, so that the intensity of thunderstorms could be expected to decrease over the urban area, as observed by Boatman *(1974)*. This may further result in precipitation anomalies observed downwind of large urban areas. The small amounts of water vapor absorbed by hygroscopic aerosols generated from industrial effluents create haze particles that severely reduce visibility in the urban area. The effect of increased moisture from industry at night when mixing is only within a shallow layer would be expected to increase urban humidity, such that the city may be more moist than surrounding country air. This may also explain the greater tendency for fog in urban areas.

Finally, now that evidence for an urban area as a potential weather modifier on the basis of its physical presence is realized, some recommendations may be offered that would help to make the city a more comfortable place in which to work and live. From energy and moisture budget considerations, green belts or vegetated areas are necessary within our cities. Green belts would not only help to embellish the downtown image, but also moderate the cities temperature. Large asphalt parking lots should be transected with trees and shrubs to reduce overheating. Fountains and small parks should be constructed within the heart of the city where the greatest percentage of concrete and impervious surfaces exist. Gardens and vegetation could be planted on rooftops. All of these modifications of the urban moisture budget would contribute to a moderation of the daytime temperature excess of the urban heat island.

CONCLUSIONS

The lack of available moisture from the urban surface leads to increased sensible heat energy and ground stored energy. Properly spaced green areas are perhaps the most important means of controlling the urban temperature excess. The urban heat island effect could also be reduced in torrid latitudes by using building materials that have lower heat conductivity and capacity. Building with different materials and colors, through changes in albedo and heat absorption, would cause differentials in heating and encourage mixing and ventilation. On the other hand, cities in high latitudes may be purposefully constructed to strengthen the heat-island effect. If the effects of urban development on the local climate are considered in the urban planning process, climate modification can be purposely controlled toward man's comfort rather than allowed to inadvertently develop to man's distress.

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Anthropogenic Moisture Production and Its Effect on Boundary-layer Circulations over New York City

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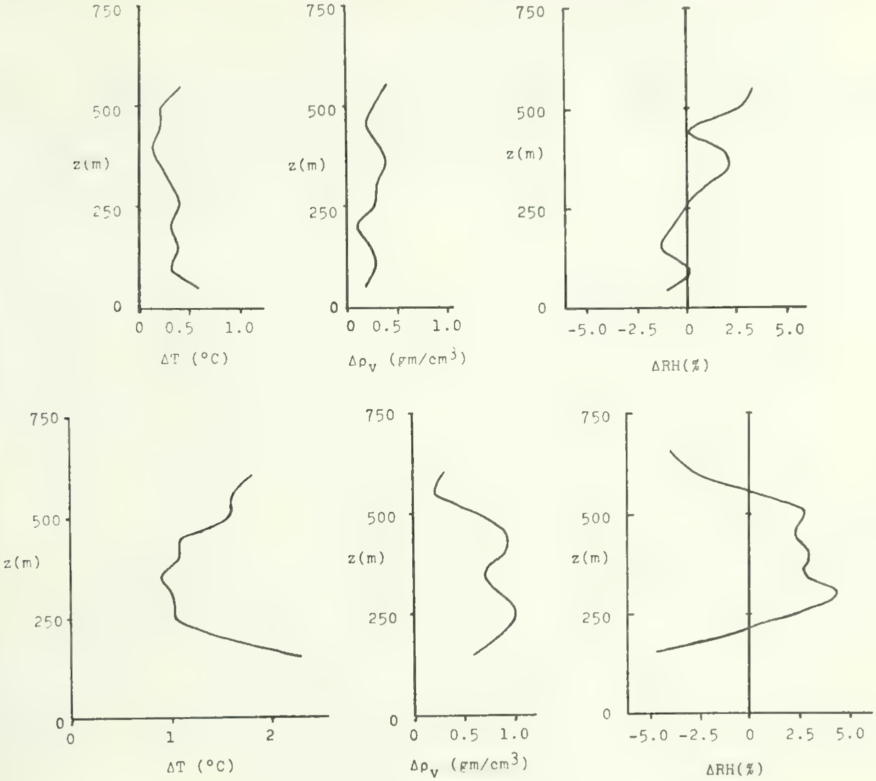
ABSTRACT.—A heat and moisture excess over New York City is shown to exist by the analysis of helicopter soundings of temperature and wet-bulb depression. The magnitude of the temporal and spatial distribution of anthropogenic moisture emissions in New York City were estimated from fuel-usage data. The URBMET urban boundary-layer model was used to evaluate the effects on the dynamics of the urban boundary layer resulting from the observed urban moisture excess. Work is currently in progress to determine the fraction of the observed moisture excess over New York that is due to anthropogenic sources.

UNTIL RECENTLY, studies of the atmospheric moisture content at the surface in and around cities have shown that, on the average, cities are somewhat drier than their rural surroundings. Average relative humidities have generally been found to be several percent lower in cities than in nearby rural areas; also, absolute humidities were found to be slightly lower in the built-up areas. The main reason given for these humidity differences was the lower evaporation rates in the city than in the country. This reduction occurs because rainfall is retained by vegetation-covered rural surfaces, while rapid runoff occurs in asphalt- and concrete-covered cities *(Peterson 1969)*.

Recently, Chandler *(1967)* obtained atmospheric-moisture data from a series of automobile transverses in and around London during three summer nights of low wind, clear skies, and well developed urban heat islands. He found that measured urban vapor pressures were higher than nearby rural vapor pressures, and found the reverse true for relative humidities. He attributed the higher nighttime urban absolute humidity to the lower amount of dew formation in urban areas and to the addition of water to the urban atmosphere from anthropogenic sources.

Similar results were found by Ackerman *(1971)* in an analysis of seven years of dew-point data from urban Midway Airport in Chicago and from rural Argonne National Laboratory, 125 miles southwest of Chicago. Results showed: (1) an urban moisture excess when all of the data were considered, (2) an urban moisture excess for the nighttime data, (3) an urban moisture deficit for the daytime data, and (4) an urban moisture excess for the winter daytime data. Thus during the times when combustion was a major source of moisture the urban atmosphere was more moist than the rural atmosphere. These results are consistent with those of Auer and Dirks *(1974)*, who found that the air over St. Louis was drier than that over its nearby rural areas during summer daytime periods. Urban moisture excesses have also been found by Kopec *(1973)* and Goldreich *(1974)*, while Hage *(1972)* showed that anthropogenic moisture emissions can enhance the forma

Figure 1.—Average vertical distribution of urban minus rural values of temperature ΔT, absolute humidity $\Delta\rho_v$, and relative humidity ΔRH for daytime periods (upper curves) and nighttime periods (lower curves).



tion of low-temperature fog in the city of Edmonton.

Vertical and horizontal moisture distributions in and around New York City were studied by Lorenzen *(1972)* and Bornstein *et al. (1972)* to determine the vertical extent of urban-rural moisture differences. Sixty-two helicopter soundings of temperature, wet-bulb depression, and pressure height were obtained during three early-morning periods and during one late-afternoon period in 1964.

Results from the analysis of the above data (fig. 1) showed that the following values are larger at night than during the day: (1) urban heat-island values, (2) urban excesses in absolute humidity, (3) urban relative humidity deficits below 250 m, and (4) urban relative humidity excesses at heights between 250 and 500 m.

The data used by Bornstein *et al. (1972)* were collected from 1964 to 1969 as part of a U.S. Public Health Service sponsored grant to the late Ben Davidson of the Department of Meteorology and Oceanography at New York University. As described by Davidson *(1967)*, the main goal of the project was to develop a sophisticated model for the prediction of the distribution of SO_2 in the New York City metropolitan area *(Shieh et al. 1969)*.

Though the data obtained by the NYU project were used in various studies of the urban boundary layer over New York City, the original data set was never published, due to the untimely death of the project's principal investigator. In the belief that NYU/NYC data set is unique, and that it could be extremely useful to persons interested in the urban boundary layer over New York City, much of the original data has recently been published by Bornstein *et al. (1975b)* under a grant from the U. S. Environmental Protection Agency and is on file with its Meteorology Laboratory at Research Triangle Park. An important component of the NYU/NYC data is an area and point-source emission inventory for the production of SO$_2$, heat, and moisture from anthropogenic sources within the New York City metropolitan area during 1965.

The main goals of the current research reported here are: (1) to determine the magnitude and variation in time and space of the anthropogenic moisture flux in New York City, (2) to determine the effects of the observed moisture excess on the dynamics of the urban boundary layer over New York City, and (3) to determine the fraction of the observed moisture excess over New York City that is due to each of the following: area-source emissions, point-source emissions, and reduced nighttime condensation rates in the urban areas, as compared to those in nearby rural areas.

The first of these goals has been carried out under a grant from the U. S. Environmental Protection Agency to the Department of Meteorology at San Jose State University, while the second part has been accomplished by use of the computer facilities at Lawrence Livermore Laboratory. The third section is currently being carried out under a grant from the National Science Foundation to the Department of Meteorology at San Jose.

In carrying out the second and third parts, the two-dimensional, nonsteady "URBMET" (for urban meteorology) urban boundary-layer model of Bornstein *(1975)* has been used to predict the temporal and spatial distribution of wind, temperature, and moisture within the urban boundary layer. The surface boundary condition for the absolute humidity in these simulations is being obtained from the temporal and spatial distribution of the anthropogenic moisture production in New York City, as obtained from the fuel-use inventory compiled during the original NYU air-pollution project.

ANTHROPOGENIC MOISTURE EMISSIONS

Most of the study region (fig. 2) has an elevation that is close to mean sea level, but the northwestern 10 percent of the area consists of highlands that range in elevation from 250 to 500 feet above mean sea level. About 30 percent of the study area is water, while 60 percent is open country, and 10 percent has been built up for urban and suburban uses.

During the original NYU project, an unpublished inventory of the annual emission of SO$_2$ from the known area and point sources in the New York Metropolitan region was compiled. Point-source emission information was obtained through the use of questionnaires, while area-source emissions from both fixed and mobile sources were computed from fuel-use data obtained from the following sources: (1) the U. S. Bureau of Mines, which publishes an annual report on the shipments of fuel oil; (2) the New York Oil Heating Association (3) the American Petroleum Institute (4) the New York City Council Committee on Air Pollution; (5) the New York City Housing Authority; (6) th New York City Air Pollution Contro Agency; (7) the NYC Fire Department; and (8) the New York City Licensing Agency, which controls th installation, registration, licensing, an insurance of each furnace or powe plant in New York City. The seven mai types of fuel consumed in the New Yor City area, the uses to which they ar put, and their annual rates of consumption are listed in table 1.

Because fossil fuels are composed o carbon, hydrogen, sulfur, etc., the com

Figure 2.—Topography of study area with values in feet above sea level. Also shown by the cross-hatched area are the built-up areas of New York City.

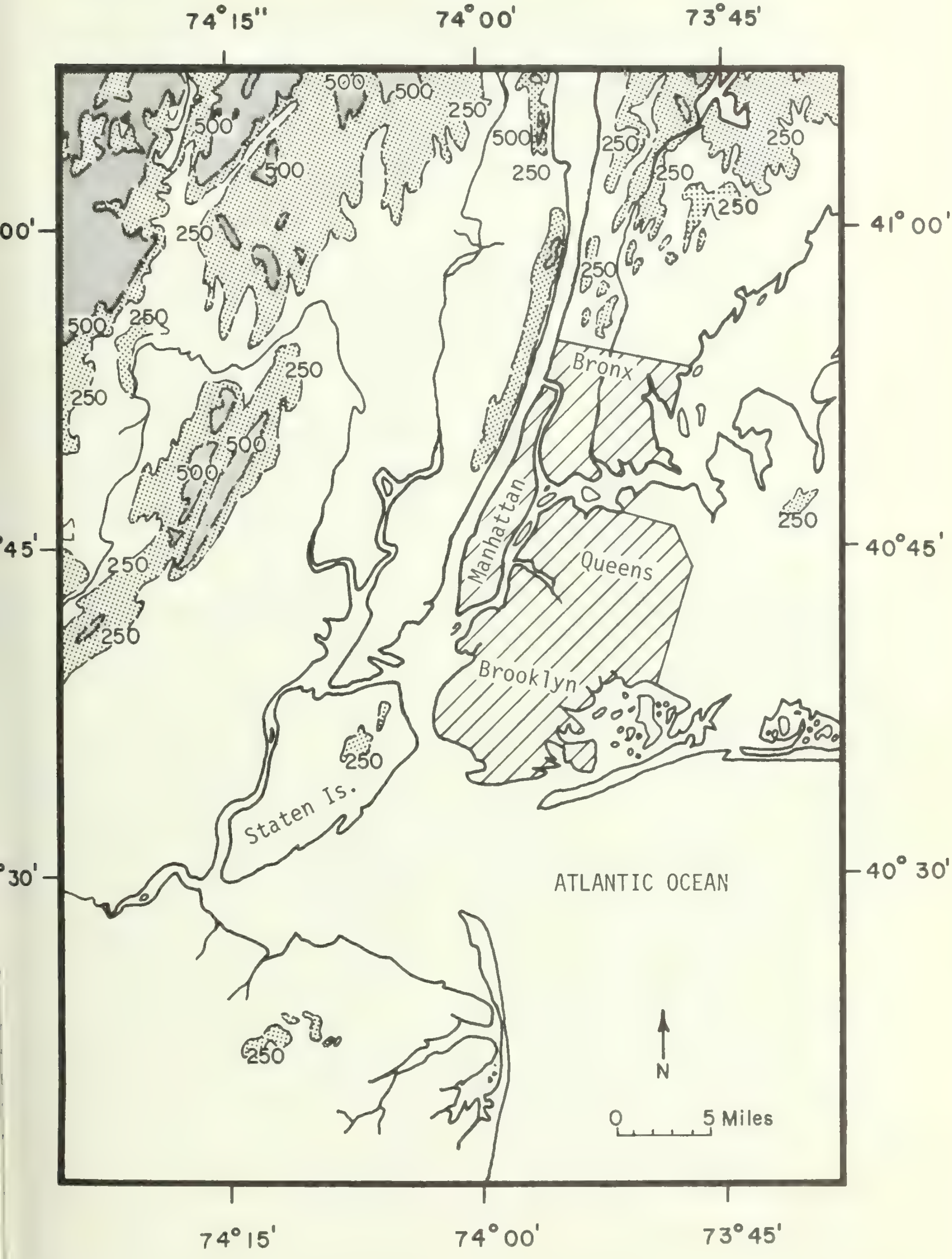


Table 1.—Fuel Consumption in New York City in 1965

Fuel type	Uses	Annual consumption
Bituminous coal	Space-heating and firing of industrial boilers	5.4×10^6 tons
Anthracite coal	Residential space-heating	0.72×10^6 tons
Distillate oil #4	Space-heating of small apartment houses	1.5×10^9 gal.
Residual oil #6	Space-heating of large apartment houses and operation of industrial plants and factories	2.6×10^9 gal.
Natural gas	Fuel in power plants, energy for industrial plants, space-heating, and home cooking	1.67×10^{11} ft.^{3}
Gasoline	Automobiles, trucks, and buses	1.1×10^9 gal.
Diesel	Automobiles, trucks, and buses	66.6×10^6 gal.

Table 2.—Composition of natural gas

Paraffin hydrocarbon	Fraction of total mass	Water content
	percent	*percent*
CH_4	93.45	186.90
C_2H_6	3.67	11.01
C_3H_8	1.78	7.12
C_4H_{10}	0.65	3.25
Others	0.45	—
Total	100.00	208.28

bustion of these fuels produces oxides of sulfur, oxides of nitrogen, carbon monoxide, carbon dioxide, aldehydes, hydrocarbons, particulates, and water vapor. The quantities of these products put into the atmosphere depend on the rate of the combustion process, the content of impurities per unit mass, the equipment used for the combustion process, and the kinds of control devices that might have been installed. For example, in the steam boilers of Consolidated Edison power plants, 1.4 lbs. of steam are added per 100 lbs. of residual oil consumed. This is done in order to atomize the oil, so as to increase the efficiency of the combustion process. Thus the water-vapor emission rate from these stacks is greater than from other point sources.

The basic equation for the production of water from the combustion of coal (after the hydrocarbons have been broken down) is

$$2H_2 + O_2 \rightarrow 2H_2O \quad . \qquad [1]$$

while the general formula for the combustion of oil and gas is

$$C_xH_y + (x+\frac{y}{4})\ O_2 \rightarrow x\ CO_2 + \frac{y}{2}\ H_2O \qquad [2]$$

where

$$y = 2x + 2 \qquad [3]$$

if the hydrocarbon C_xH_y is saturated. Thus for coal, one gram of hydrogen produces 18 grams of water, while Y grams of H_2 per mole of gas or oil produces 18Y/2 or 9Y grams of water per mole, where 18 is the ratio of the molecular weights of water and hydrogen.

The water production from each component of natural gas (table 2) was evaluated by multiplying the coefficien of the final term of equation 2; i.e., Y/2, by the percentages in the middle column of the table. Water-production factors for each of the seven fuel types used in New York City are shown in table 3 where the liquid water content of coal is determined by drying under standar conditions for 1 hour at 104 to 110 C.

The five boroughs of New York City (identified by name in figure 1) were gridded into 1 by 1 mile areas, and the following equation was used to evalua

Table 3.—Composition by percent of total mass of the fuels used in New York City

Fuel type	H_2O (%)	Gaseous H_2O (%)	Liquid H_2O (%)	Total H_2O (%)	H_2O released per unit
Bituminous coal	5.14	46.26	2.0	48.26	0.4826 lb/lb
Anthracite coal	2.70	24.30	2.2	26.50	.265 lb/lb
Distillate oil	11.63	104.67	—	104.67	7.955 lb/gal
Residual oil	11.63	104.67	—	104.67	8.478 lb/gal
Natural gas	—	208.28	—	208.28	.11 lb/ft^3
Gasoline	15.00	135.00	—	135.00	9.315 lb/gal
Diesel	15.00	135.00	—	135.00	9.315 lb/gal

Table 4.—Percentage of SO_2 emitted from each fuel type in each Borough of New York City

Fuel type	Bronx	Brooklyn	Queens	Manhattan	Staten Island
Bituminous coal	1.45	8.61	32.53	37.26	70.80
Anthracite coal	2.16	1.34	.39	1.31	1.29
Distillate oil #4	8.60	13.91	10.26	1.13	5.99
Residual oil #6	87.18	75.69	56.05	59.88	21.53
Natural gas	.01	.01	.01	.01	.01
Gasoline	.39	.29	.48	.28	.22
Diesel	.21	.15	.28	.13	.16
Total	100.00	100.00	100.00	100.00	100.00

the magnitude of the annual anthropogenic moisture production M_A from each of the grid areas:

$$M_A = \sum_{i=1}^{7} \frac{S_A \bullet P_i \bullet M_i}{S_i}, \qquad [4]$$

Definition and units for symbols are found at one end of this paper.

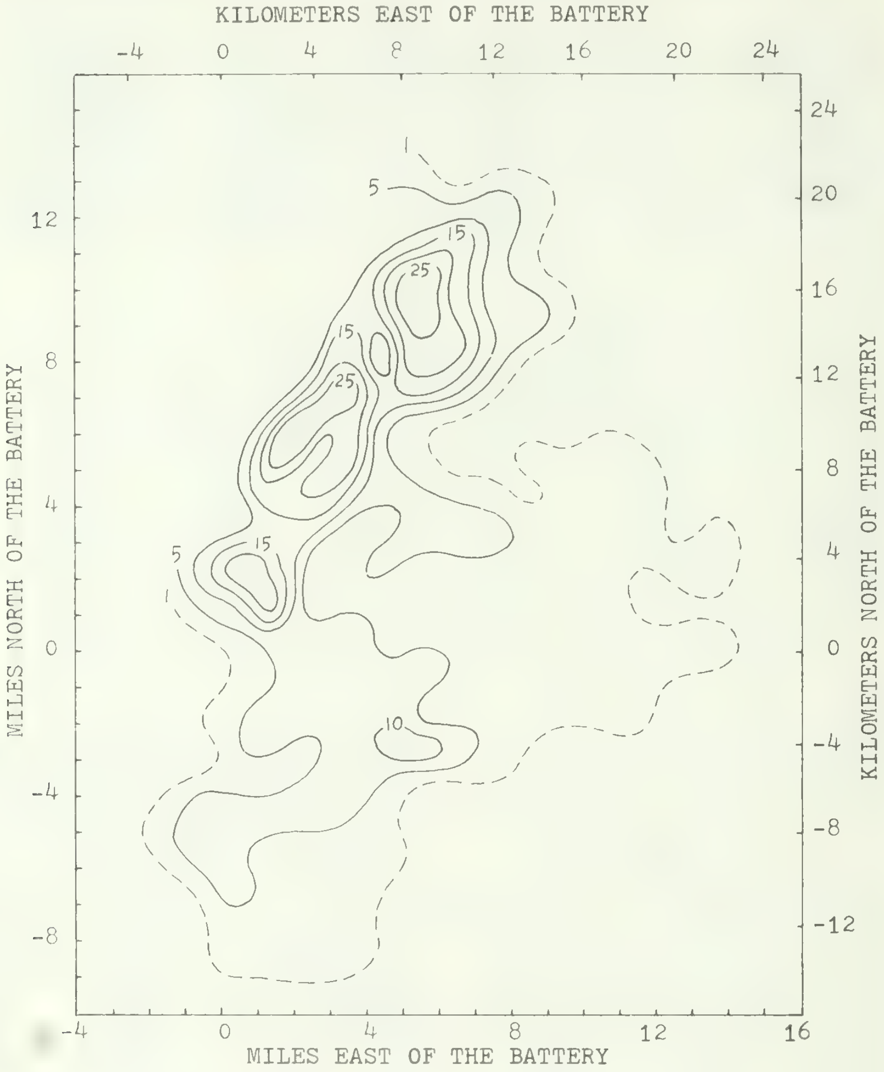
Note that the product of S_A (from the unpublished SO_2 inventory — now published by Bornstein *et al. (1975b)* — and P_i (table 4) gives the annual emission of SO_2 from the i-th fuel in a particular grid in tons per year. Values of P_i were kept constant in each borough because the use of each fuel in all of the grid areas was not available. Where the values were available, a random check showed that the magnitudes of P_i in a given borough were within ± 5 percent of the mean values used in Equation 4. The product of S_A times P_i divided by S_i (table 5) gives the annual use of the i-th fuel in the particular grids, while values of M_i (table 3) include the release of gaseous and liquid moisture.

Table 5.—Fuel type, sulfur content by weight, and sulfur emission factors for the seven fuel types used in New York City

Fuel type	Sulfur content (%)	SO_2 emission factor
Bituminous coal	1.875	75.0 lb/ton
Anthracite coal	.625	25.0 lb/ton
Distillate oil	.575	85.0 lb/10^3 gal
Residual oil	2.450	390.0 lb/10^3 gal
Natural gas	4 ppm	.6 lb/10^6 ft^3
Gasoline	.030	5.0 lb/10^3 gal
Diesel	.300	45.0 lb/10^3 gal

Annual area-source (fixed and mobile) emissions of anthropogenic moisture in New York City in 1965 in 10^{10} gm per year (fig. 3) were obtained by the summation of the seven partial emission rates of Equation 4. The origin of the grid used in the figure is at Battery Park, which is at the southern tip of Manhattan. The annual emission data were converted into average hourly fluxes (fig. 4), which have the units of 10^{-5} gm cm^{-2} hr^{-1} and can be used as

Figure 3.—Isopleth analysis of anthropogenic moisture production from area sources in New York City, in 10^{10} grams per year.


KILOMETERS EAST OF THE BATTERY
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-4
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KILOMETERS NORTH OF THE BATTERY
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0
-4
-8
MILES NORTH OF THE BATTERY
-4
0
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16
MILES EAST OF THE BATTERY
1
5
15
25
15
25
5
15
10

the lower (flux) boundary conditions in a numerical boundary-layer model of the urban atmosphere, as is being done by Tam *(1975)*.

Because some areas in New York City are source-free (such as Central Park and rivers around Manhattan), the fluxes of the previous figure were recomputed in terms of emission intensities; i.e., the emission of H_2O per unit of production area per time. This increased the maximum emission from 2.2 x 10^{-5} gm cm^{-2} min^{-1} to 4.3 x 10^{-5} gm cm^{-2} min^{-1}. The second valu corresponds to a 22.6-cm-per-year annual evaporation rate, which is about 2 percent of the annual evaporation rat in the coastal Atlantic off of New Yor City *(Jacobs 1951)*.

For studies requiring a more detaile emission pattern, the above computations were repeated on 0.5 by 0.5-mil area-source grid over Manhattan *(Bornstein et al. 1975b)*, the region of maximum H_2O emission. In computing th emission rates for the finer grid, th

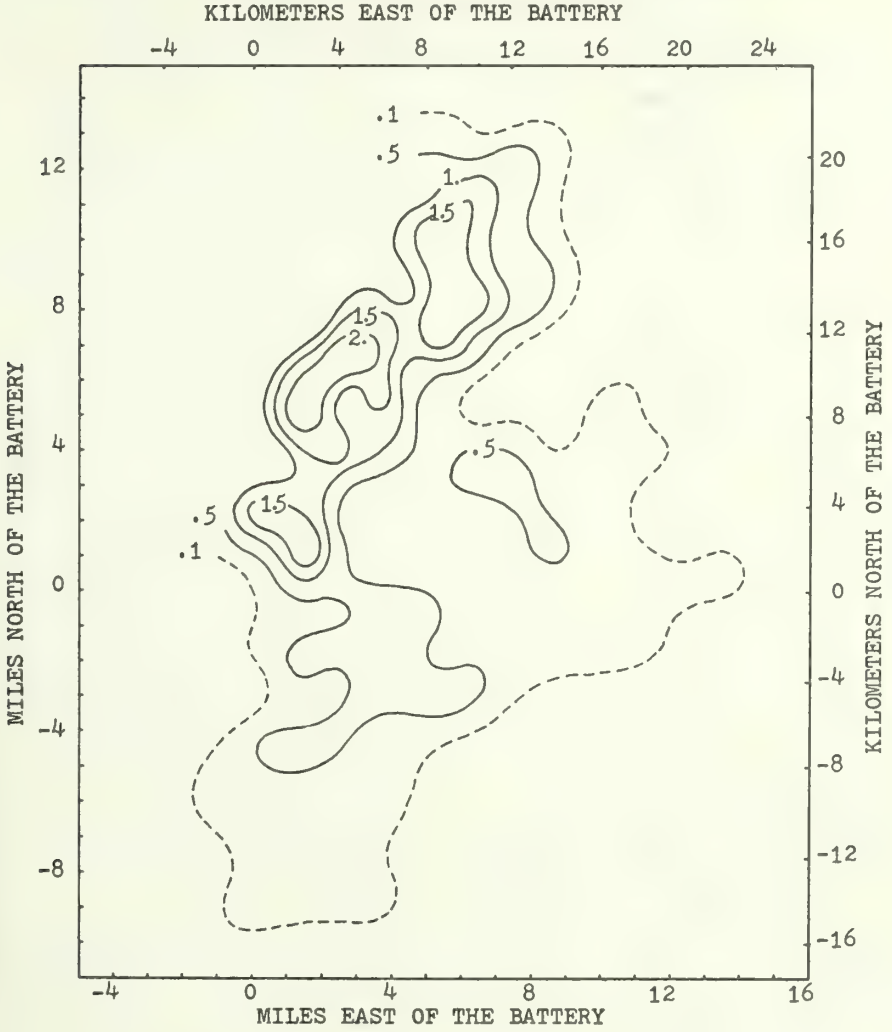

Figure 4.—Isopleth analysis of anthropogenic moisture production from area sources in New York City, in 10^{-5} gm cm^{-2} min^{-1}.

KILOMETERS EAST OF THE BATTERY
-4
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MILES NORTH OF THE BATTERY
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-8
KILOMETERS NORTH OF THE BATTERY
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.5
.1
1.5
.5
MILES EAST OF THE BATTERY
-4
0
4
8
12
16

emissions from the larger areas were assumed to be homogeneously distributed over the built-up areas of the city, while emissions from the rivers around Manhattan and from Central Park were aken to be zero.

Anthropogenic moisture production in New York City by borough (table 6) hows that Staten Island contributes nly a small fraction of the total area-ource emission in New York City (and ence it is not cross-hatched in fig. 1), while Queens contributes the maximum mount of any borough. Production by fuel type (table 7) shows that residual oil produces more moisture in New York City than does any other fuel type, while production by source type (table 8) shows that domestic space-heating produces a larger amount of anthropogenic moisture than any other source type.

Estimates of the hourly emission rates of anthropogenic moisture from the fixed, but not mobile, area sources in New York City were made by using data obtained from timers attached to boilers located in selected buildings. The resulting data were used by Halpern

Table 6.—Anthropogenic moisture production in New York City by borough

Borough	Production (10^{12} gm/year)	Percentage of total
Queens	10.13	33
Brooklyn	8.60	28
Manhattan	7.06	23
Bronx	3.99	13
Staten Island	0.92	3
Total	30.69	100

Table 7.—Anthropogenic moisture production in New York City by fuel type

Fuel type	Production (10^{12} gm/year)	Percentage of total
Bituminous coal	2.35	7.7
Anthracite coal	.17	.6
Distillate oil	5.05	16.4
Residual oil	9.93	32.3
Natural gas	8.32	27.1
Gasoline	4.59	15.0
Diesel	.28	.9
Total	30.69	100.0

Table 8.—Anthropogenic moisture production in New York City by source type

Source type	Production (10^{12} gm/year)	Percentage of total
Domestic	10.91	35.5
Industrial	1.78	5.8
Government & commercial	4.18	13.6
Power plants	8.95	29.2
Motor vehicle	4.87	15.9
Total	30.69	100.0

et al. (1971) to relate the number of minutes per day that the boilers were in operation to the degree-day value D computed as follows:

$$D = 65 - \bar{T}, \quad \bar{T} \leqslant 65,$$

or [5]

$$D = 0 \quad , \quad \bar{T} > 65,$$

where T is the average daily temperature of a given day in °F.

The boiler-timer data were then used by Halpern et al. *(1971)* to develop the following equation, which relates the daily emission rate of H_2O from a particular area source to the annual emission rate from that area source:

$$M_D = \frac{0.7}{4871} D + \frac{0.3}{365} M_A. \quad [6]$$

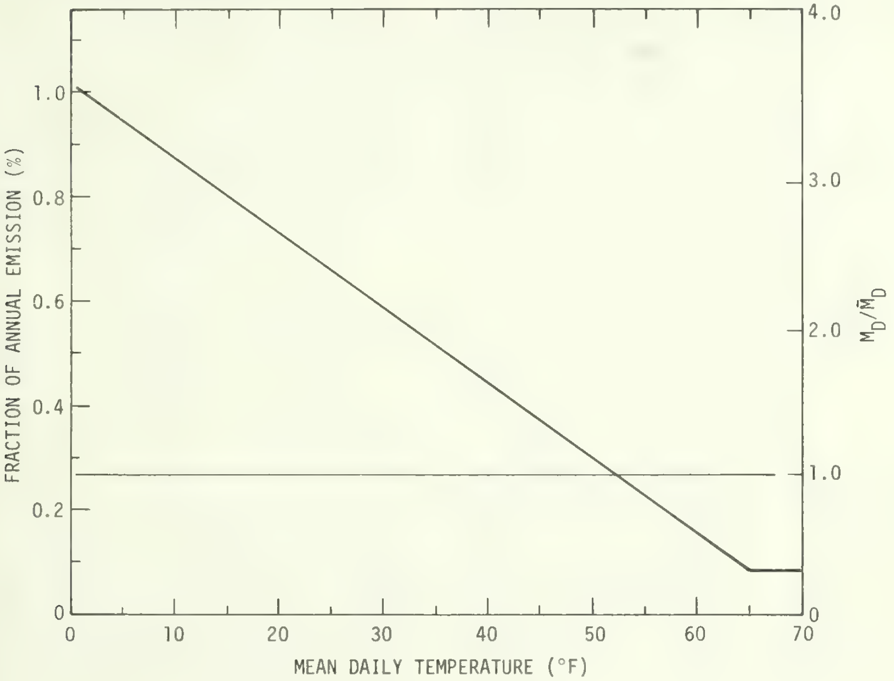
The above relationship shows that 30 percent of the annual emission of H_2O from each area source is due to the production of hot water at a uniform rate throughout the year. The remaining 70 percent is due to space-heating, which is dependent on the average daily temperature. Note that the annual sum of the daily degree-day values for New York City is the 4871 appearing in the equation.

If M_A were spread uniformly over the year, then on each day 0.27 percent of the total would be emitted. However, when Equation 6 is used to prorate M_A according to $\bar{T}$ (fig. 5), it is found that the value of $(M_D/M_A) \cdot 100$ percent varies linearly from 1.02 percent for a T of 0°F to 0.08 percent for a $\bar{T}$ equal to or greater than 65°F. Thus the emission on a cold day can be as much as an order of magnitude greater than that on a hot day.

The same boiler-timer data were used by Halpern *et al. (1971)* to develop curves showing the diurnal variation in winter, when most of the fuel is consumed for space-heating, and in summer, when most of the fuel is used fo the production of hot water in the hour near sunrise and sunset. These result were used by Leahey and Friend *(1971* to compute the spatial distribution o the annual and daily production of ar thropogenic heat in New York fror area sources due to fossil fuel use. The can be used to produce the same ir formation for the anthropogenic moi ture flux in New York City.

In the New York City area in 196 there were 378 point sources of SO_2 th were found to have an annual emissi rate of at least 100 tons of SO_2. The 2 point sources within the city emitt

Figure 5.—Fraction of annual area-source emission of moisture in New York City as a function of mean daily temperature. Also shown is the ratio of the daily emission M_D to the uniform daily emission $\bar{M}_D$ (shown as the horizontal line).



3.67 x 10^5 tons of SO_2 per year, or about one-half of that emitted by the area sources within the city.

In general, the rate of consumption by power plants, industrial processes, and automobiles changes only slightly throughout the year. However, the emission rates of some industrial and commercial sources do vary significantly over the year, and the emission rates of many point sources do have a diurnal variation. Where it was available, this information has been tabulated by Bornstein *et al.* (*1975b*), as has been the stack height and heat-emission data needed in plume-rise calculations. Thus he NYU/NYC data set contains the in-ormation needed to evaluate the area-ource and point-source emissions of nthropogenic moisture in New York ity for use as the surface flux boundary ondition for moisture in an urban oundary-layer model of New York City.

NUMERICAL SIMULATIONS

In the basic URBMET model, finite difference solutions to the vorticity and energy equations are obtained in a vertical plane in the direction of a constant geostrophic wind. The vertical fluxes of heat and momentum are assumed to be constant with height in a lower, analytical, surface-boundary layer, while they generally decrease with height in an upper, numerical finite-difference, transition layer.

The transition layer is assumed to be hydrostatic and Boussinesq, the latter assumption implying incompressible flow. All lateral gradients are assumed to be zero, except for that of the undisturbed pressure, which corresponds to a constant geostrophic wind. Adiabatic motions are also assumed, while diffusion effects in the direction of the geostrophic wind are assumed to be insignificant as compared to advective effects. Initially, adiabatic lapse rates are assumed, as the heat-island simulations are assumed to commence at 1800 LST. The eddy-exchange coefficients used in the transition layer in URBMET are computed from a third-order-polynomial. Details on the formulation of the model can be found in Bornstein *(1975)*.

One modification of the original URBMET model in the current study was the inclusion of a continuity equation for water vapor, under unsaturated conditions, given by

$$\frac{\partial q'}{\partial t}=\frac{\partial (uq')}{\partial x}+\frac{\partial (wq')}{\partial z}+\frac{\partial}{\partial z}\left(K_q\frac{\partial q'}{\partial z}\right) \quad , \qquad [7]$$

where K_q was taken equal to K_H. Because of this equality, the surface layer profiles for q' are identical to those for θ', if q and q^* replace θ and θ^*, respectively, in the various surface boundary layer equations in B. In addition, the potential temperature θ is replaced by the virtual potential temperature θ_v. The two are related by

$$\theta_v=[1+0.61\ q]\theta \quad , \qquad [8]$$

where each of the three variables, in the absence of any initial variations, can be given by the sum of a space average constant and a perturbation quality resulting from the urban induced circulations. If

$$\theta' << \theta_m \quad , \qquad [9]$$

it can be shown that

$$\theta_v' \approx \theta' + 0.61\ \theta_m q' \quad , \qquad [10]$$

and thus θ'_v replaces θ' everywhere in the model equations given in B. The second change in URBMET was concerned with the choice of the magnitude of the time step used in integration, and this is discussed in Bornstein and Robock *(1975a)*.

An interlaced grid was used in this study, as it considers velocity components to be the average inflow and outflow rates on horizontal and vertical elements of a cube. Previous studies have discussed the superiority of variable grid spacing in achieving high resolution near the surface and near discontinuities in surface characteristics. Accordingly, the 16 by 16 grid network used in the present study (table 9) possesses such a spacing near the surface, and in the vicinity of the city. A list of the boundary conditions on q currently used is given below.

Table 9.—Grid locations for θ, u and v grid points, with height above the surface z indexed by j, and distance from the center of the urban area x indexed by i

j/i	z (m)	x (km)
1	0	—30
2	12.5	—20
3	37.5	—12.5
4	62.5	— 7.5
5	87.5	— 5.0
6	125	— 2.5
7	175	0
8	225	2.5
9	275	5.0
10	325	7.5
11	375	10.0
12	450	15.0
13	600	22.5
14	850	32.5
15	1200	47.5
16	1650	67.5

$$q'=a(x,t) \quad , \quad z=0 \quad , \qquad [11$$

$$\text{continuity of } q' \text{ and } \frac{\partial q'}{\partial z} \quad , \quad z=h \qquad [12$$

$$q'=0 \quad , \quad z=H \quad , \qquad [13$$

$$\frac{\partial (uq')}{\partial x}=0 \quad , \quad \text{upwind boundary} \quad . \qquad [14$$

At each time step, following an i itialization process described below, th following is performed: determinati of the new values of θ'_v and q' at the su face; construction of the constant fl layer using the latest values of θ'_v, q', ar U at the surface, and at the lowest fini difference grid; and determination the new q' θ'_v, ζ, Ψ, u, w, v, and U field respectively, using the newest availa values of all parameters and done in manner described in Bornstein and Robock *(1975a)*.

The initial conditions were considered to be those at the beginning of an urban heat-island episode (at 1800 LST), and thus the following initialization procedure was carried out. First, the URBMET model was used to simulate the one-dimensional, neutral, dry planetary boundary layer over homogeneous terrain by assuming the following conditions

$$\frac{\partial}{\partial x} = w = 0 \qquad [15]$$

$$\gamma = \Gamma \qquad [16]$$

$$\theta_v' = 0 \qquad [17]$$

$$q' = q_m = 0 \qquad [18]$$

Justification of the assumption contained in Equation 16 for the hours near 1800 LST can be found in the observations obtained over cities *(Bornstein 1968)*, as well as in those from rural O'Neill, Nebraska *(Kuo 1968)*.

Simulations were carried for values of the surface roughness parameter z_0 of 1 and 3m, and for values of the geostrophic wind u_g of 3 mps. The values for z_0 were chosen to be typical of areas with buildings of one and six stories *(Lettau 1969)*. The simulations were carried out using a constant value of 15 sec for the time step of integration, and were concluded when equilibrium conditions were obtained; i.e., when the final accelerations of the damping inertial oscillation were less than 0.1 cm ec $^{-1}$ hr $^{-1}$.

The resulting equilibrium wind profiles were then used as the initial conditions for simulations reproducing the wo-dimensional equilibrium distributions of wind over a rough city under onditions of neutral stability. Thus, the onditions expressed in equation 15 were o longer used, but as the results of these new simulations provided the initial conditions for the heat-island simulations discussed below, the conditions shown in equations 16 to 18 were still used.

Two-dimensional equilibrium wind distributions for the rough city cases were obtained after 3 hours of simulated time, using an equal advection and diffusion time step of 15 sec. The results of these simulations showed that the values of the total horizontal wind speed at the urban sites at heights up to several hundred metres were reduced in magnitude below those at corresponding heights at the upwind rural boundary. The maximum difference in speed occurred at the first grid point above the surface and over the downwind half of the city. The maximum upward and downward values of the corresponding vertical velocities were associated with the areas of maximum convergence and divergence at the upwind and downwind edges of the city, respectively.

Simulations were carried out to reproduce effects on the structure of the urban boundary layer, during the hours from 1800 to 1000 LST, resulting from higher urban than rural values of z_0 and surface temperature, but not q'. Hence, the conditions expressed by equations 16 and 17 were no longer used, but equation 18 was still applied.

The urban and rural surface cooling rates were estimated from the observations in and around urban Montreal by Oke and East *(1971)*. These observations indicated that the rural atmosphere near the surface cooled rapidly in the evening hours before midnight, while the urban atmosphere near the surface was maintained at a nearly constant temperature during the same period. After midnight both regions cooled at about 50 percent of the rate found at the rural site before midnight. Therefore, the magnitude of the heat island near the surface increased with time in the early evening and then remained constant until morning. Thus the following surface cooling and warming rates were assumed:

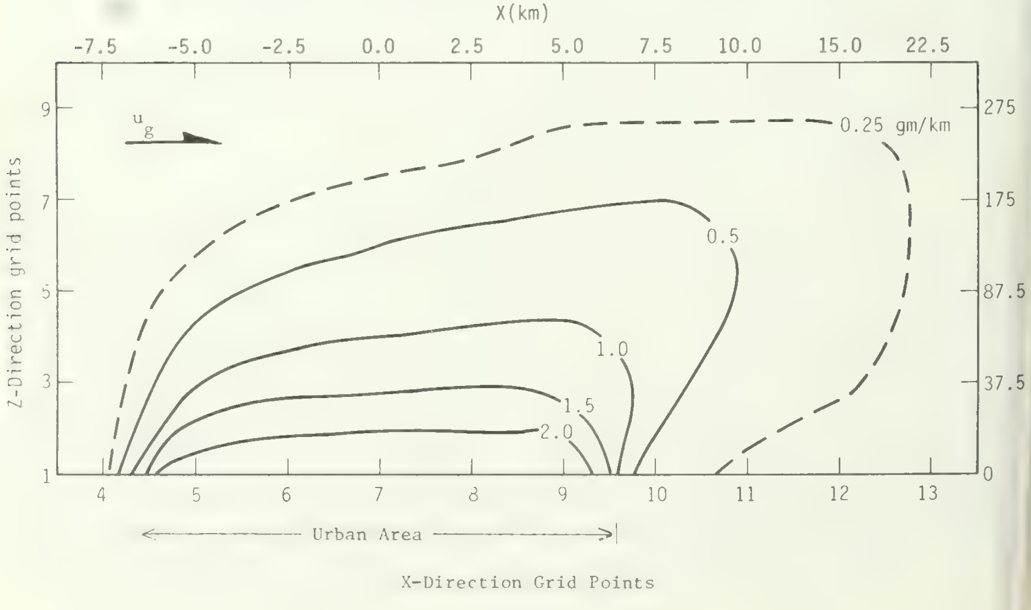
Period (LST)	Urban ($C\ hr^{-1}$)	Rural ($C\ hr^{-1}$)
1800-2400	0.0	−1.0
2400-0600	−0.5	−0.5
0600-1000	1.0	3.0

These simulations were carried out by using a variable time step for both the advective and diffusive processes *(Bornstein and Robock 1975)*. The cooling rates prescribed above caused formation of a surface-based inversion in the rural areas, and the advection of cool rural air over the uncooled urban surface during the first 6 hours of the simulations caused formation of a slightly unstable layer near the urban surface. During the second 6 hours of simulation, the decreased surface-cooling rates slowed the rate of increasing stability at rural sites, while the urban cooling was unable to completely overcome the effects of advection, and thus Richardson numbers in the city remained slightly negative.

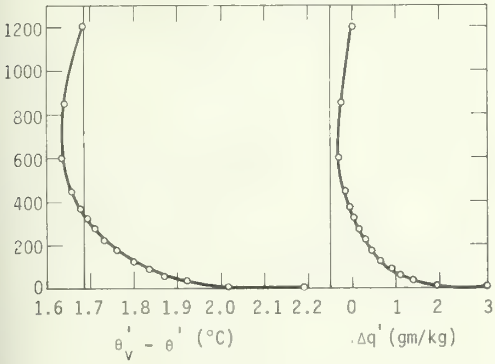
The horizontal wind field resulting after 6 hours of simulated time showed a region of decreased wind speeds, as compared to those at the upwind rural boundary. This region was found upwind of, and above, a region in which speeds are higher than those at the upwind boundary. A smaller region of decreased speeds was also seen downwind of the city near the surface. The corresponding vertical velocity field showed a region of sinking air over the city, sandwiched between two regions of upward motion.

The final simulations were carried out to reproduce the effects of an anthropogenic source of moisture on the structure of the urban boundary layer. Thus, the conditions expressed by equation 18 are no longer used; instead th background level of moisture q_m wa arbitrarily set equal to 10 gm kg^{-1}. I addition, it was assumed that the surface value of q' at the urban grid point increased by 0.25 gm kg^{-1} hr^{-1}.

Figure 6.—Distribution of the perturbation specific humidity q' in gm km^{-1} after 12 hours of simulated time; i.e., at 0600 LST, for the flow over a warm, rough, wet city; values represent the deviation from those at the upwind boundary. Parameters include a geostrophic wind of 3 mps, a rural z_0 of 1 metre, and an urban z_0 of 3 metres.



igure 7.—Vertical variation of $\Delta q'$, the dif-erence between the values of q' over the ownwind urban edge and those at the up-ind model edge, at 0600 LST for the run iscussed in figure 6. Also shown is the ver-ical variation of θ_v'-θ' at the upwind model oundary (thin vertical line) and at the down-ind urban edge (thick curve).



The excess moisture thus placed into he urban atmosphere was advected and iffused vertically and/or horizontally, s expressed by equation 7. A typical istribution of q' after 12 hours of simu-ated time at 0600 LST (fig. 6) shows he effects of the advection and diffusion.

The vertical variation of the differ-nce between the values of the pertur-ation specific humidity q' over the ownwind urban edge and those at the pwind model edge at 0600 LST (the ighthand half of figure 7) produces a uoyancy effect, as wet air is less dense han dry air. This enhances the buoy-ncy produced by the urban heat-island ffect. At the same height above the urface, the magnitude of the buoyancy roduced by the urban moisture excess t any point is given by the difference etween the value of θ'_v - θ' at the upwind odel boundary and that at the point ig. 7). From these values, and from e values of the total predicted buoy-cy due to the heat-island effect was mputed. The results (table 10) in-cate that, near the surface, the addi-nal buoyancy due to the moisture ex-ss is about 10 percent of that due to e heat-island effect.

However, observations of the moisture excess over New York City by Bornstein *et al. (1972)* indicate that the moisture excess of the urban atmosphere in the present simulation could be increased by a factor of two. Even with the amount of anthropogenic moisture currently specified, there is a noticeable increase in the magnitude of the urban breeze effect (fig. 8) at the center of the urban area. The maximum increase of ΔU in the case of an urban moisture excess (case 2) over those from the case of no urban moisture excess (case 1) is about 8 cm sec^{-1}, or about 15 percent.

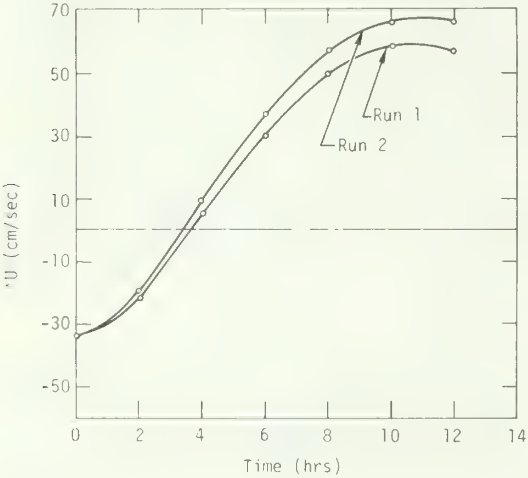
SUMMARY

A heat and moisture excess over of New York City has been shown to exist by use of helicopter soundings of temperature and wet-bulb depression. For three early morning flights, the moisture excess was about 0.9 gm m^{-3}, which represented an increase of about 10 percent over values at nearby rural sites. The humidity and moisture excesses were generally highest over the central part of the city, and then decreased over the peripheral urban areas, implying the existence of a heat and moisture dome over New York City.

Table 10.—Height variation of the temperature [illegible]nce due to the urban moisture excess $\Delta\theta_1$, and due to the urban heat island $\Delta\theta_2$, at a site located at the downwind urban edge.

z (m)	$\Delta\theta_1$ (°C)	$\Delta\theta_2$ (°C)
0	0.5	5.8
12.5	.3	4.7
37.5	.2	2.5
67.5	.2	2.0
87.5	.1	1.7
125.0	.1	1.4
175.0	.1	1.0
225.0	.1	.8
275.0	.0	.7
325.0	.0	.6
375.0	.0	.4
450.0	.0	.3
600.0	.0	.1
850.0	.0	.0

Figure 8.—Time variation of the horizontal wind speed at a height of 125 m. Values represent the differences in cm sec^{-1} between the values at the upwind model boundary and those at the downwind urban edge for the two cases discussed in the text. The values of u_g and z_0 are those given for figure 6.



The magnitude of the temporal and spatial distributions of anthropogenic moisture emissions in New York City from fixed and mobile area sources were estimated using fuel-use data collected during the NYU/NYC urban air-pollution dynamics project of 1964-69. The maximum annual emission rate from a particular square mile in Manhattan was found to be equal to about 25 percent of the annual evaporation rate in the coastal Atlantic off of New York City.

The URBMET urban boundary-layer model was used to evaluate the effects on the dynamics of the urban boundary layer resulting from the buoyancy associated with an observed urban moisture excess. Results indicated that the buoyancy produced by the moisture excess was about 10 percent of that produced by the urban heat-island effect. This excess buoyancy enhanced the strength of the urban-breeze effect by about 15 percent over what had resulted due to the heat-island effect alone.

Work is currently in progress to determine the fraction of the observed nighttime moisture excess over New York City that is due to each of the following: area-source emissions of moisture, point-source emissions of moisture, and reduced nighttime condensation rates in the urban areas, as compared to those in nearby rural areas. In this work, the flux of anthropogenic moisture into the atmosphere is used as a surface boundary condition for the URBMET boundary-layer model.

There is no completely satisfactory method of incorporating area and point-source emissions of moisture into a boundary-layer model. In previous models area sources of heat have been included in surface energy balances, even though some of this energy enters the atmosphere through the sides and tops of buildings. In addition, point sources cannot be represented in two-dimensional finite difference boundary-laye models, which can only treat line an area sources. Thus work remains to b done in order to accurately represent th effects of anthropogenic heat and moisture on the structure of the urba boundary layer.

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LIST OF SYMBOLS

Variables and Constants—Roman Alphabet

a(x,t)	Specified variation of the surface specific humidity
h	Top of constant flux layer, equal to 25 m
H	Top of transition layer, equal to 1900 m
i	Horizontal index for horizontal wind and temperature grid
j	Vertical index for horizontal wind and temperature grid
K	Generalized eddy transfer coefficients in $cm^2\ sec^{-1}$
K_H	Eddy transfer coefficient for heat in $cm^2\ sec^{-1}$
K_q	Eddy transfer coefficient for moisture in $cm^2\ sec^{-1}$
M'_A	Annual emission of moisture from a particular area source, in gm per year
M_A	Same as M'_A, but in $gm\ cm^{-2}\ sec^{-1}$
M_D	Daily emission of moisture from a particular area source grid, in $gm\ cm^{-2}\ sec^{-1}$
M_i	Moisture emission factor for the i-th fuel
p	Atmospheric pressure in $dynes\ cm^{-2}$
p_m	Constant space average of pressure in $dynes\ cm^{-2}$
p_o	Variation of pressure in absence of perturbation motion in $dynes\ cm^{-2}$
p′	Fluctuation of pressure due to perturbation motion in $dynes\ cm^{-2}$
P_i	Percent of total SO_2 emission in a grid from use of the i-th fuel
q	Specific humidity in grams of moisture per grams of moist air

q_m, q_o, q'	See pressure definitions
q^*	Friction specific humidity in grams of moisture per grams of moist air
S_i	SO_2 emission factor for i-th fuel
t	Time in sec
T	Temperature in K
T_m, T_o, T'	See pressure definitions
u	Horizontal component of wind in the x-direction in cm sec^{-1}
u_g	Geostrophic wind in x-direction in cm sec^{-1}
u^*	Friction velocity in cm sec^{-1}
U	Total horizontal wind speed in cm sec^{-1}
v	Horizontal component of wind in the y-direction in cm sec^{-1}
w	Vertical component of the wind in cm sec^{-1}
x	Horizontal coordination in direction of geostrophic wind in cm
y	Horizontal coordinate in direction perpendicular to the geostrophic wind in cm
z	Vertical coordinate for vorticity in cm
z_o	Aerodynamic roughness length in cm

Variables and Constants—Greek Alphabet

Γ	Dry adiabatic cooling rate, equal to 9.8 K km^{-1}
ζ	Modified y-component of vorticity in sec^{-1}
θ	Potential temperature in K
θ_m, θ_o, θ'	See pressure definitions
θ_v	Virtual potential temperature in K
θ'_v	Perturbation virtual potentia temperature in K
θ^*	Friction potential temperatur in K
Ψ	Stream function in cm^2 sec^{-1}
Δ	Difference operator

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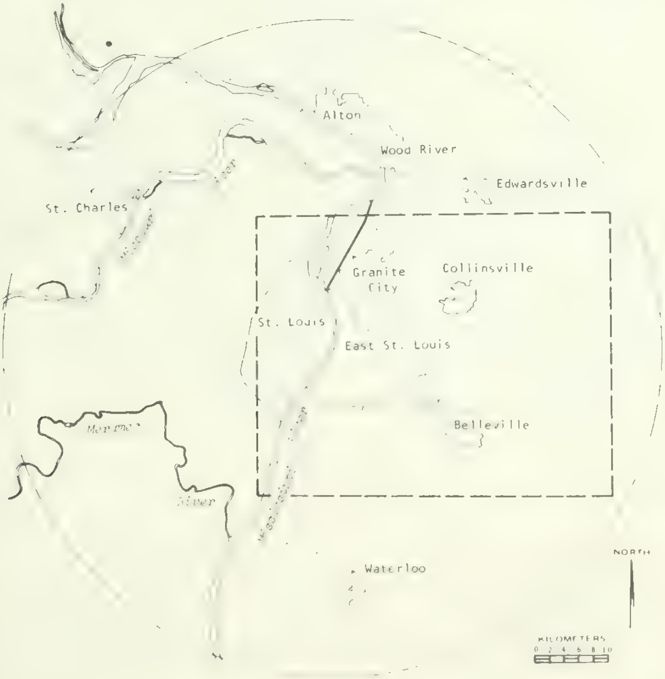
Temporal and Spatial Variability of Rainfall pH

by RICHARD G. SEMONIN, *assistant head, Atmospheric Sciences Section, Illinois State Water Survey, Urbana, Ill.*

ABSTRACT.—The distribution of average rainwater pH over an area of 1,800 km^2 containing 81 collectors was determined from 25 storm events. The areal average of the data was pH 4.9, with a range of values from 4.3 to 6.8. A single storm event was studied to determine the change of pH as a function of time. The initial rain was pH 7.1, decreasing to 4.1. An excellent agreement was observed between the H^+ deposition rate and the rainfall rate.

THE STUDY OF PRECIPITATION chemistry is an essential component f the METROMEX (METROpolitan leteorological EXperiment) research n inadvertent weather modification at t. Louis, Mo. Through the use of chemcal tracers and analytical techniques, it as been established *(Semonin 1972)* hat materials released from near the urface are processed, scavenged, and deposited by migratory storm systems in an area defined in climatological studies of Huff and Changnon *(1972)* as the St. Louis precipitation anomaly. The chemistry research is directed toward the estimation of convective cloud scavenging efficiency by the analysis of several elements found in rainwater, but also includes the occasional measurement of pH and conductivity.

Figure 1.—The St. Louis METROMEX field project research area. The dashed rectangle delineates the precipitation chemistry network.



Much of the land area within the METROMEX research circle (fig. 1) is in agriculture, and the deposition of the hydrogen ion in a localized high-rainfall area is a feature of inadvertent weather modification pertinent to crop production in proximity to urban centers. In addition, the effect of pH on the quality of storm runoff water and shallow groundwater supplies is a subject requiring serious attention as continued industrial development proceeds.

The data presented here begin to address these problem areas by illustrating the local variability of precipitation pH. An evaluation of the impact of such pH variability on regional planning, crop production, and local water supplies is treated. Though these impacts are extremely important, the nearly total lack of validation of rainwater pH effects on agriculture and water quality relegate this paper to presenting data with little interpretation of its meaning to longer-range problems of environmental quality.

DATA COLLECTION

Twenty-five convective storm days in the summers of 1972 and 1974 comprise the data set. The area studied covers 1,800 km^2 and contains a network of 81 rainwater collectors and 3 sequential rain samplers described by Gatz et al. *(1971)*.

The network samplers consist of a 1-liter polyethylene bottle fixed to a metal farm fencepost by an adjustable large-diameter hose clamp. The samples were collected within 2 hours after cessation of precipitation and transported to the laboratory facility for analysis within 36 hours. The pH was determined immediately upon arrival of the sample in the laboratory and before any preparations for subsequent elemental analysis by atomic absorption spectrophotometry.

The sequentially collected samples were treated in the same way as those from the network. However, these samples were acquired as a function of rainfall rate by a tipping-bucket arrangement in a housing containing 72 collector bottles. The bucket emptied into polyethylene bottles after sufficient volume of rain fell on the 1-m^2 collection surface (usually ½ liter), and the local time was recorded for each collection event. The recorded time interval for the sample collection was used to calculate the rates of deposition for the precipitation, various elements, and the hydrogen ion.

AREAL VARIABILITY

The pH determinations from each site for all 25 storm events were combined to provide an average distribution over the sampling network. The average pH values were calculated by first computing the total grams of hydrogen ion deposited by the 25 storms and dividing by the total water collected. The results (fig. 2) show that it is difficult to envision a direct relationship betwee known SO$_2$ sources (fig. 3) and the area pattern of the pH.

The area of pH $\leqslant$ 4.5 can, of course be qualitatively related to the concentration of point sources along the Mississippi River in St. Louis and E. St. Louis Likewise, the small area of pH $\leqslant$ 4. near Granite City coincides with the indicated nearby sources. However, th large areas of pH $\geqslant$ 6.5 over the S Louis urban center, and the low p values in the southeastern corner of th network do not correlate well wi known industrial operations. The ove all average pH for the entire 1,800-kr area determined by combining t measurements for all storms from sampling sites was 4.9

An examination of the frequency pH $\leqslant$ 4.5 (fig. 4) was made to dete mine the persistance of low pH val at each site. The high frequency in t southeastern corner of the network mains an anomaly and requires verifi tion by additional data. The remaini centers of frequent occurrence can attributed to SO$_2$ sources in proxim

Figure 2.—The rainfall-weighted average pH pattern derived from 25 storms. The areal mean is 4.9 with a range of values from 4.3 to 6.8.

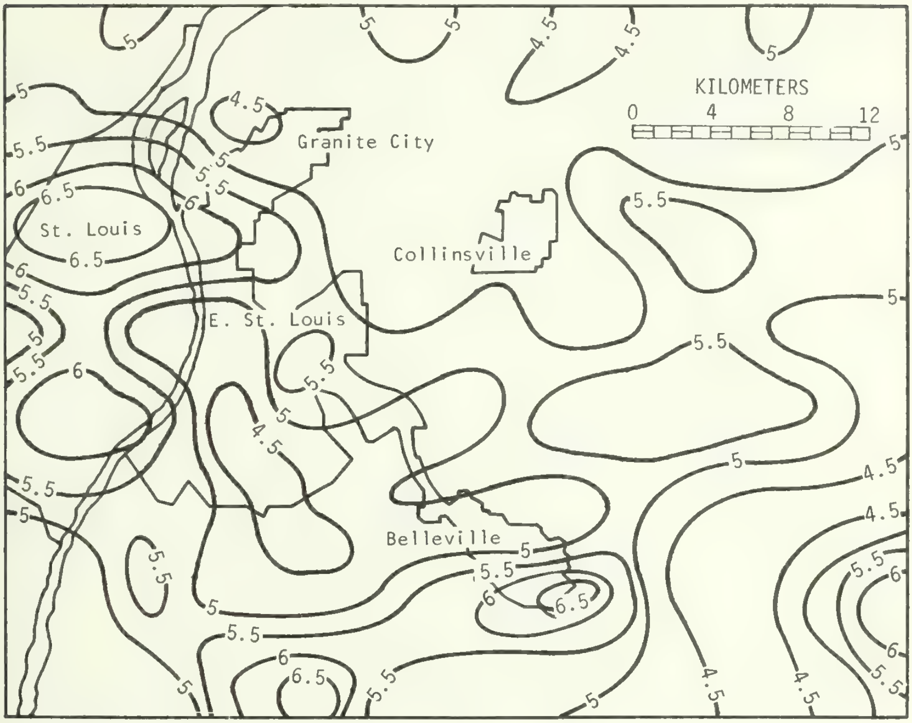


Figure 3.—The location and estimated sulfur oxide source strength in proximity to the chemistry network.

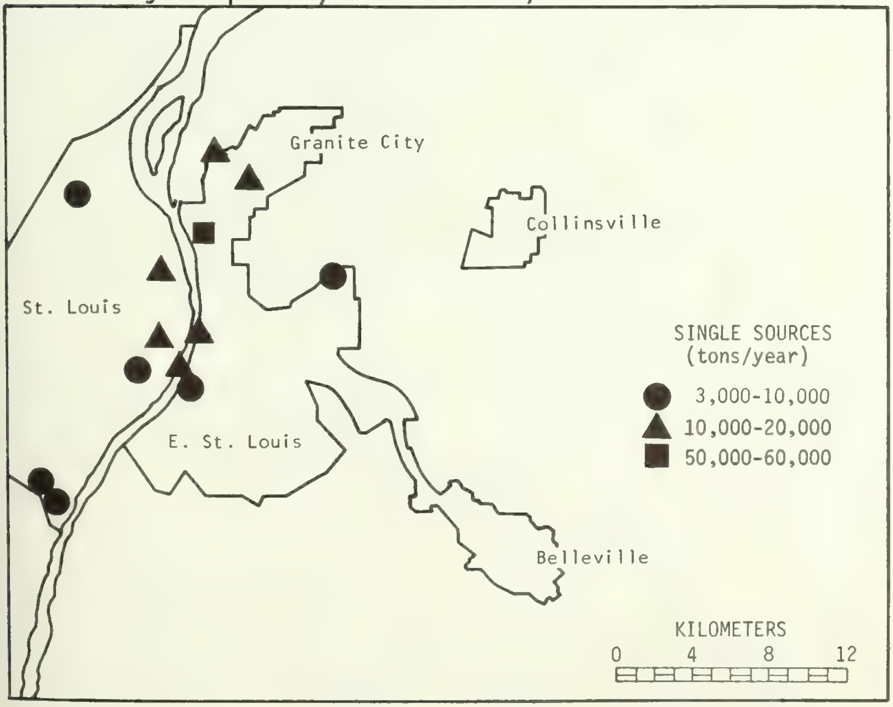
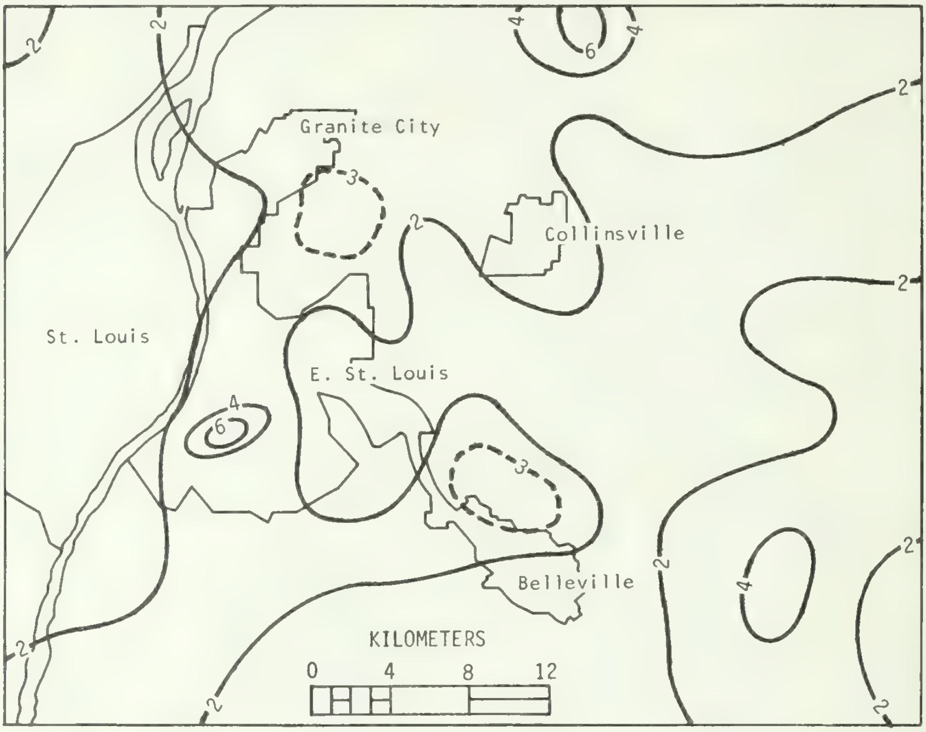


Figure 4.—The point frequency of pH ≤ 4.5 from the 25 storm data set.



The value near Edwardsville may be due to the Wood River refineries 10 km northwest of the network. It is interesting to note that only 15 to 25 percent of the rain samples in these areas produced the average pH values ≤ 4.5.

The average rainwater (fig. 5) associated with the 25 storm events is consistent with the concept of inadvertent precipitation modification by an urban complex. The historical records for the St. Louis region indicate a rainfall anomaly extending north to south approximately 15 to 25 km east of the Mississippi River. Even the small sample of storm events used for this study indicates an average high rainfall in the anomaly area, which points to the problems of selecting data-collection sites.

The hydrogen ion deposition (fig. 6) calculated from the pH and rain volume shows somewhat better spatial correlation with the SO_2 sources. However, the removal processes by convective storms are extremely complex and variable, resulting in a spatial averaging an smoothing of the observed rainfall an pH data. The results from METROME *(Huff 1973)* indicate two major areas o importance to inadvertent precipitatio modification. The first of these is th city of St. Louis; the second is th Alton-Wood River industrial comple The latter is not included within the ne work boundaries, and the contributio of Alton-Wood River to the pH variabi ity can only be surmised at this time.

The deposition pattern can be e visioned as consisting of three bands relatively high deposition oriented a proximately north to south and sep rated by 15 to 20 km. Though th orientation is not unlike that of orga ized convective storm systems, there no meteorological explanation for t apparent banded structure of depositi A superficial comparison between t patterns of average rainfall (fig.

Figure 5.—The average rainfall from the 25 convective storms used in this study, in milliliters.

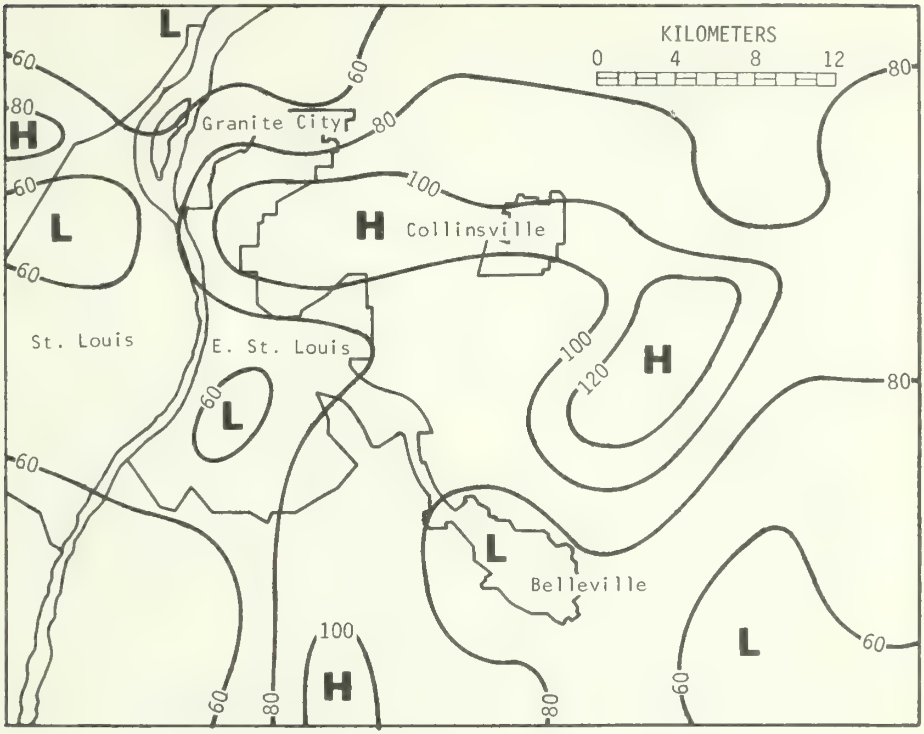


Figure 6.—The average H+ deposition calculated from the rainfall and pH measurements, in micrograms.

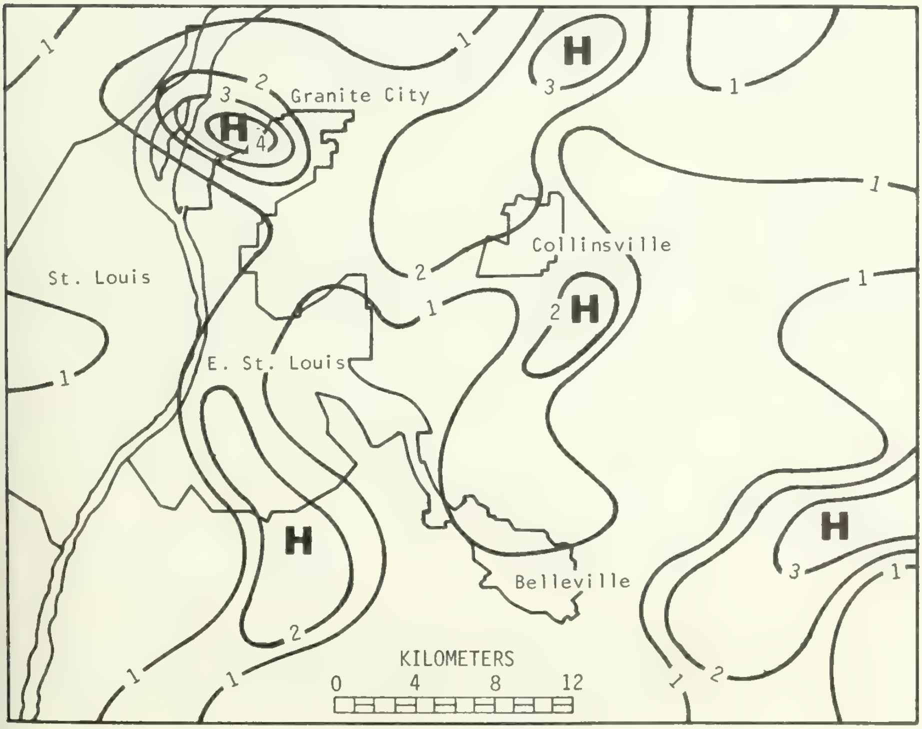
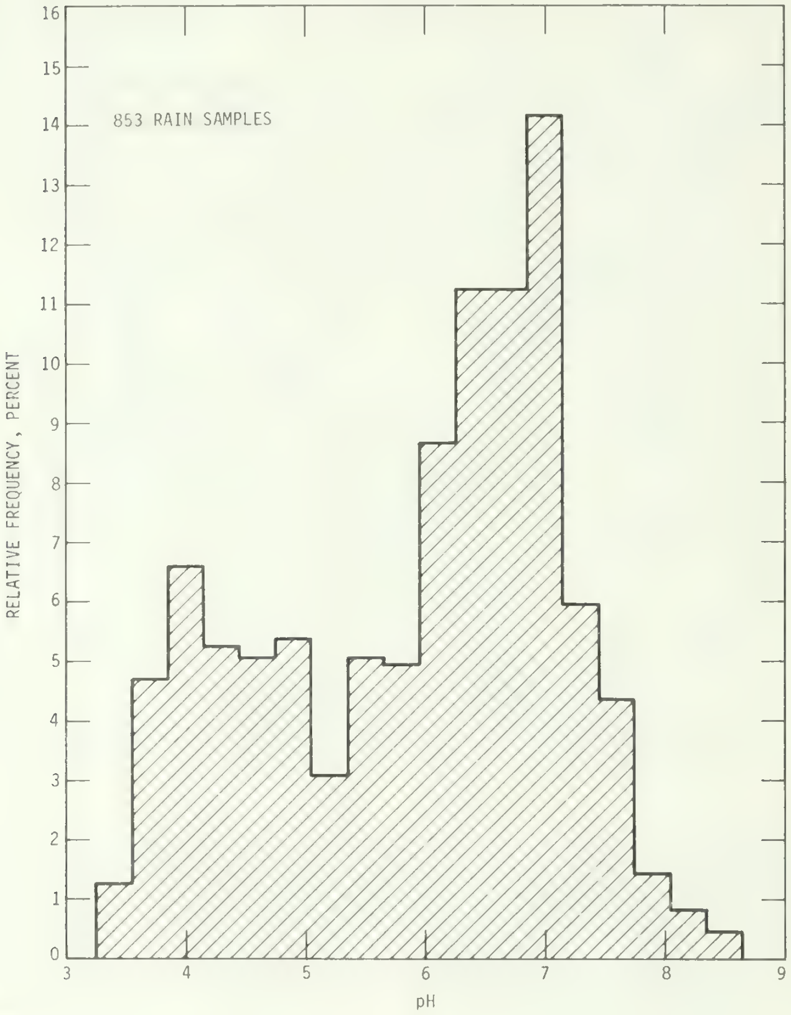


Figure 7.—The relative frequency distribution of rainwater pH from 25 storms in 1972 and 1974.



and average pH (fig. 2) suggests little correlation and emphasizes the independence of these two variables. Consequently, it is necessary to measure both the total rainfall and the pH to assess the potential environmental response to acid rainfall.

The relative frequency of pH (fig. 7) obtained by combining all 853 observations from the network is another way of illustrating the variability of acid rainfall. The most striking feature of this analysis is the high frequency of neutral rainfall and the secondary peak at 4.2 pH. This secondary peak is created by the relatively few sites tha undergo frequent low pH precipitatio as previously described. Further measurements are necessary, however, to determine the precipitaton pH frequenc in other seasons of the year when urba and industrial emissions may be qui different from those during the summ months.

TEMPORAL VARIABILITY

The potental impact of pH on the e vironment cannot be fully determined study of bulk rain samples as acquir from the network. For example, all t

H-determining compounds could be de-
osited either at the beginning or at the
nd of a convective storm, with different
mplications as to the expected effects.

The data obtained on 3 August 1972
xemplify the temporal change of pH
nd the changes of rainfall rate (fig. 8).
'hroughout the first 45 minutes of rain
he pH decreased dramatically from 7.1
o 4.1 while the rainfall rate remained
elatively constant between 1 and 7mm
r^{-1}. The independent, nearby total rain
ample had a pH of 3.9. Apparently the
igh pH of the initial light rain was
nsufficient to neutralize the later more
ntense and more acid precipitation.

The measurements from other storm
vents show opposite temporal change
f pH; that is, increasing from low
alues to relatively constant values. This is an important feature of precipitation deposition of materials, making it possible to estimate the time rate of change of deposition. Since the concentration approaches a constant shortly after the initiation of a storm event at a point, the variation of the deposition rate is directly related to the preciptation rate (fig. 9). Therefore, as a first approximation for the depiction of the rate of hydrogen ion deposition, simple measurements of total storm rainfall pH and rainfall rate are all that is required.

SUMMARY AND DISCUSSION

The areal variability of average pH appears to be independent of the average rainfall variability and cannot be related easily to known SO_2 sources. With the exception of a few sites, the

Figure 8.—The variation of pH (closed circles) with time during the convective storm of 3 August 1972. The nearby total storm sample pH of 3.9 is indicated by the horizontal line. The rainfall rate (open circles) in millimeters per hour is shown for reference.

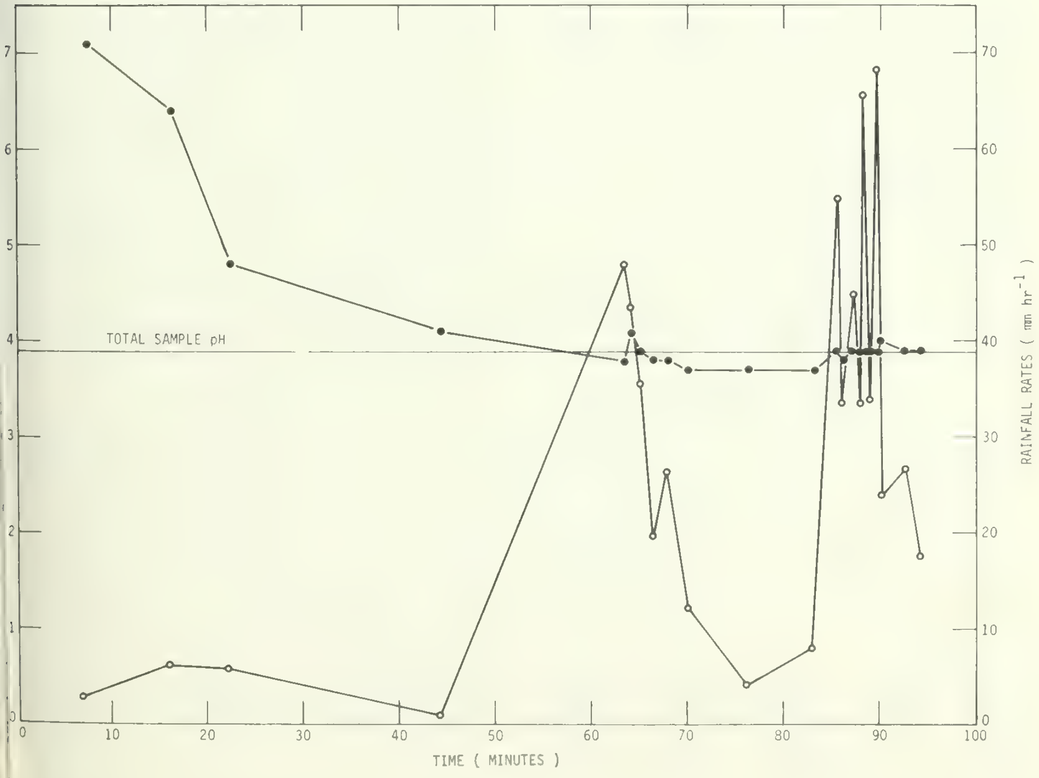
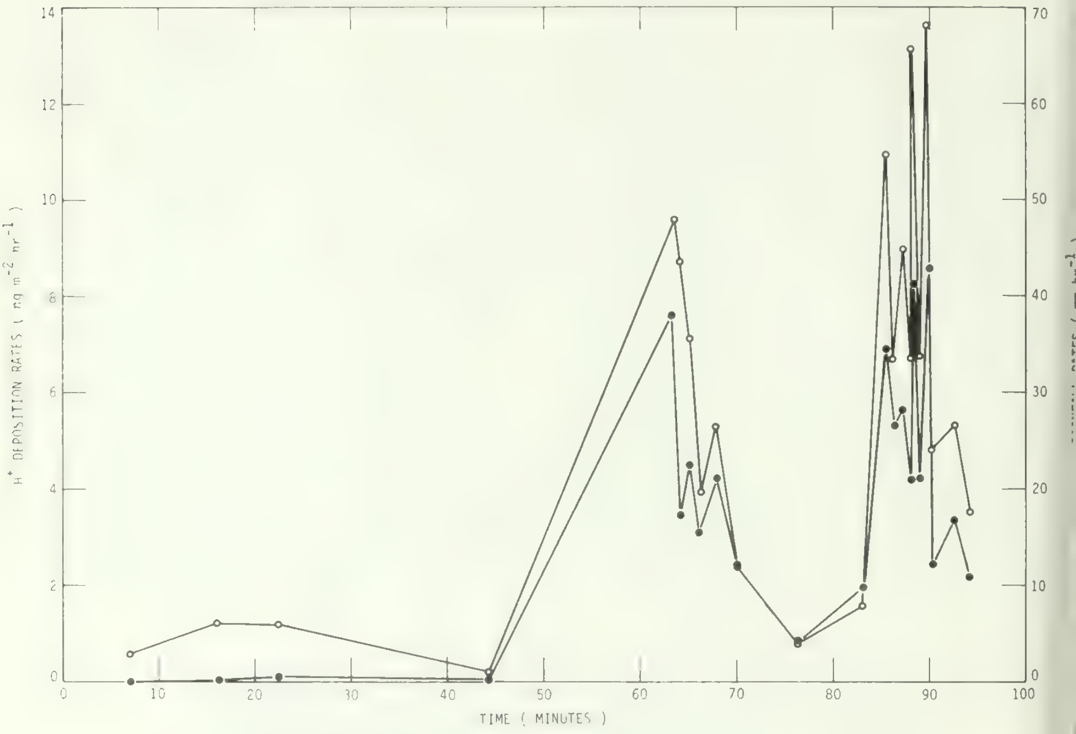


Figure 9.—The H^+ deposition rate (closed circles) and rainfall rate relationship for the storm of 3 August 1972.



most frequently observed pH was 7.0, indicating that acid rainfall is not an extremely serious problem in the 1,800-km^2 area immediately east of St. Louis. These data do point out the difficulties with regard to point measurements, and suggest that any conclusions regarding long-term trends must be viewed cautiously. The average pH may vary from an acid value ($\leqslant$ 4.0) to an alkaline value over a distance of a few kilometers.

The study of the temporal change of pH in convective precipitation further complicates the assessment of the variability. The case study presented showed a three-unit change of pH during the initial 45 minutes of a storm, with little subsequent change. During the period of nearly constant pH, the rainfall rate varied rapidly throughout the storm duration.

The observations reported here illustrate certain problems that must be treated in discussions on acid rainfall. The first is related to the desired use o the data. For the study of precipitatio chemistry without regard to environmental impact, the long-term monitoring of pH from a single site may b acceptable. However, when the ultimat utility of pH data for the soil scientist water quality expert, agriculturalist, and many other potential users is con sidered, these data show that single-sit observations can lead to erroneous re lationships between environmental de gradation and precipitation.

The second problem area addressed i this paper is the relationship betwee the time-varying and total storm rai water pH. The measurements sho variations of pH during the storm to b as large as the spatial variations. Ther fore, the study of the response of the e vironment to the acid content of pr cipitation must carefully consider su wide variations both in space and tin

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Effect of Urbanization on the Thermal Structure in the Atmosphere

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ABSTRACT.—An unsteady two-dimensional transport model was used to study the short-term effects of urbanization and air pollution on the thermal structure in the urban atmosphere. A number of simulations for summer conditions representing the city of St. Louis were performed. The diurnal variation of the surface temperature and thermal structure are presented and the influences of various parameters are discussed.

IT IS ESSENTIAL in air-pollution forecasting to understand how urbanization and the urban area modify the atmospheric environment not only in the immediate vicinity of the city, but also for a considerable distance downwind. Modification of the environment takes on many forms and includes alteration of the wind, temperature, and water-vapor profiles as well as the surface temperature and the injection of gaseous and particulate pollutants into the atmosphere.

During the past few years, many serious atempts have been made to observe and explain the microclimatic effects over and around urban areas. The best-documented and least-questioned climatic effect is the urban influence on temperature in the atmosphere. The urban heat-island phenomena is clearly a result of the modification of surface and atmospheric parameters by urbanization, which in turn leads to an altered energy balance. The possible causes of the heat island are well recognized *(Peterson 1969)*, but the individual effects such as physical and radiative property differences between urban and rural areas, flow changes caused by the roughness elements, man-made heat sources and radiatively participating pollutants have not been sufficiently studied, and their quantitative influences are not completely understood.

Observational programs and mathematical modeling are needed to gain understanding of the urban environment. Unfortunately, the very nature of the urban environment necessitates extensive measurements over large distances and long periods of time, which are not only difficult but also costly. Therefore mathematical models can be employed to advantage to help fill the observational gap by numerically simulating the transport processes in the atmosphere. To the extent that the mathematical model simulates the rea atmosphere, it can then become a valuable tool for use in micrometeorologica weather prediction, forcasting of pollution episodes, urban planning, interpretation of field data, and identificatio of pollutants by means of remote sensing methods.

In addition to the above, numerica simulations can also be used as a guid for observational programs such as th Regional Air Pollution Study (RAPS sponsored by the U. S. Environmenta Protection Agency (EPA) for the S

Louis Metropolitan area. The main advantage of a numerical simulation lies in its ability to predict what will happen for any given changes in urban parameters, boundary, or initial conditions.

In this paper we will describe the short-term effects of urbanization on the thermal structure in the atmosphere of an urban area, using an unsteady two-dimensional transport model. The emphasis is on the potential effects of urbanization and air pollution on the thermal structure in the urban planetary boundary layer. As a specific example, results of numerical simulations of the city of St. Louis for summer conditions are discussed. Results of similar experiments have been reported *(Pandolfo et al. 1971, Atwater 1972, Bornstein 1972, Wagner and Yu 1972,* and *Atwater 1974).*

NUMERICAL MODEL

Physical Model and Assumptions

In the unsteady two-dimensional transport model (fig. 1), the earth-atmosphere system is assumed to be composed of four layers: (1) the free (natural) atmosphere where the meteorological variables are considered to be time-independent; (2) the polluted atmosphere (the planetary boundary layer, PBL), where the meteorological variables such as the horizontal, vertical, and lateral wind velocities, temperature, water vapor, and pollutant concentrations are functions of time, height, and distance along the urban area; (3) the soil layer, where the temperature is assumed to be a function of depth and time only (the soil and interfacial radiation properties are allowed to vary in the horizontal direction); and (4) the lithosphere, where the temperature is assumed to be constant during the simulation period. The atmosphere is assumed to be cloud-free, and no variation of topography is accounted for along the urban area.

In the polluted urban planetary boundary layer the transport of momentum, energy, and species takes place by vertical and horizontal advection as well as by vertical and horizontal turbulent diffusion. In addition, radiative energy is transported in the solar (short-wave)

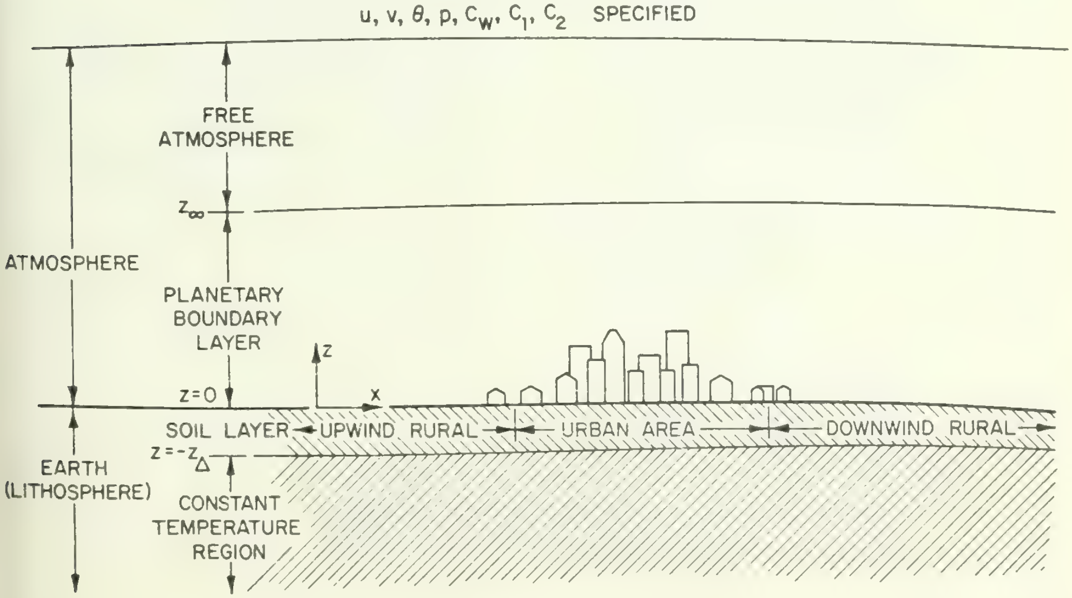


Figure 1.—Schematic representation of the urban environment and of influences analyzed by the urban boundary layer model.

and thermal (long-wave) portions of the spectrum. The interaction of both natural atmospheric constituents and gaseous as well as particulate pollutants with solar and thermal radiation is accounted for. The planetary boundary layer and soil layer are coupled by energy and species balances at the atmosphere-soil interface. The horizontal variation of the urban parameters such as man-made heat and pollutant sources, surface solar albedo (reflectance) and thermal emittance, surface roughness, thermal diffusivity and conductivity of the soil, and Halstead's soil moisture parameter are arbitrarily prescribed functions of position along the urban area. It has been observed *(Stern et al. 1972)* that the man-made heat and pollutant sources, for example, vary during the diurnal cycle. However, more realistic modeling of these sources during the diurnal cycle must await more complete observational data.

Model Equations

The numerical model is based on the conservation equations of mass, momentum, energy, and species. The equations used to describe the planetary boundary layer can be written in a general form as

$$\frac{\partial \phi_i}{\partial t}+u\frac{\partial \phi_i}{\partial x}+w\frac{\partial \phi_i}{\partial z}=\frac{\partial}{\partial x}\left(K_{xi}\frac{\partial \phi_i}{\partial x}\right)+\frac{\partial}{\partial z}\left(K_{zi}\frac{\partial \phi_i}{\partial z}\right)+S_i(x,z,t) \qquad [1]$$

where t, x, and z are the time, horizontal, and vertical coordinates; u and w are the horizontal and vertical velocity components; $\phi_i(x,z,t)$ is the dependent variable "conserved;" $S_i(x,z,t)$ is the appropriate source term; and K_{xi} and K_{zi} are suitable turbulent diffusivities. The independent variables and their corresponding sources are listed in table 1. A general discussion of the conservation equations was given by Plate *(1971)*, and Johnson *(1975)* presented a detailed derivation of the equations used in the model.

The boundary conditions prescribed at the edge of the outer flow (top of the PBL) and at the soil surface are the following: at the edge of the outer flow, ϕ_i is specified; at the interface, $u = v = w = 0$; and the surface temperature (at any x) is predicted from an energy balance

$$[1-r_s(x)]F_s(x,0)+e_t(x)F_t(x,0)-e_t(x)\sigma T^4(x,0)+\left(k+\rho c_p K_z^{\theta}\right)\left.\frac{\partial\theta}{\partial z}\right|_0+L\rho\left(D_w+K_z^{C_w}\right)\left.\frac{\partial C_w}{\partial z}\right|_0-k_g(z)\left.\frac{\partial T_g}{\partial z}\right|_0+Q=0 \qquad [2]$$

In this equation, the first two terms account for absorption of solar and thermal radiation, the third term represents thermal emission, the fourth and fifth terms account for sensible and latent heat transfer by molecular and turbulent diffusion, the sixth term rep-

Table 1.—Dependent variables and source terms

	ϕ_i		S_i
1	u	horizontal velocity	$f(v-v_g)$ geostrophic deviation
2	v	lateral velocity	$f(u_g-u)$ geostrophic deviation
3	θ	potential temperature	$\partial F/\partial z$, q radiative and man-made heat sources
4	C_w	water-vapor concentration	$\dot{C}_w$ water vapor emission
5	C_1	concentration of pollutant aerosol	$\dot{C}_1$ pollution emission
6	C_2	concentration of gaseous pollutant	$\dot{C}_2$ pollution emission

resents heat conduction into the ground, and the final term is the man-made surface heat flux. The water vapor concentration at the surface is prescribed by Halstead's moisture parameter *(Pandolfo et al. 1971)* by the expression

$$C_w(x,0) = M(x) C_{w,sat}[T(x,0)] + [1-M(x)] C_w(z_1,0) \qquad [3]$$

where M is the moisture parameter, $C_{w,sat}$ is the water-vapor concentration at saturated conditions, and z_1 is the first grid point above the surface. For a prescribed pollutant flux at the surface, m_n, a species balance at the interface, yields the condition

$$m_n = -\left(D_n + K^{C_n}\right) \frac{\partial C_n}{\partial z}\bigg|_0 \quad , n=1 \text{ and } 2 \qquad [4]$$

At the upwind boundary, the meteorological variables are predicted from the unsteady one-dimensional model of Bergstrom and Viskanta *(1973a)*. Initially, ϕ_i is specified everywhere and is assumed to be independent of the horizontal coordinate x.

Turbulent Diffusivities

Specification of turbulent diffusivities for an urban atmosphere in connection with numerical modeling of the PBL is a very difficult task and has been discussed in a recent review *(Oke 1973a)*. The semi-empirical equations developed by Pandolfo et al. *(1971)* were initially employed. The decay of turbulence in the upper part of the PBL was prescribed by following Blackadar's *(1962)* formulation. However, in the hours before sunrise, when the atmosphere became quite stable, unrealistically deep surface inversions resulted and the Richardson numbers were found to exceed the critical value.

In these situations the diffusivities predicted by Pandolfo's eddy diffusivity-Richardson number correlations were not applicable. Therefore, the cubic polynomial developed by O'Brien *(1970)* and used by Bornstein *(1972)* was employed for the prediction of the diffusivities in the transition layer under stable conditions.

Stable conditions were assumed to exist when the average Richardson number in the lowest 25 m of the atmosphere was greater than zero. Where this condition was reached, Pandolfo's model was used only near the surface, while the polynomial was employed in the transition layer. Otherwise, Pandolfo's model was used throughout the entire PBL. If the Richardson number exceeded the critical value, it was reset to this value so that unreasonable diffusivity values would not be predicted.

Radiative Transfer Model

The radiative transfer model used has been discussed in detail elsewhere *(Bergstrom and Viskanta 1973b)*, so only a summary of it is included here. The urban atmosphere is considered to be cloudless, plane-parallel, and consisting of two layers: (1) the free atmosphere, and (2) the urban PBL where the pollutants are concentrated. The earth's surface was considered to emit and reflect radiation as prescribed functions of wavelength. Since the atmospheric gases and particles absorb, emit, and scatter radiation, the radiative transfer between the free atmosphere and the PBL is coupled. However, no consideration is given to individual point sources of pollutants. Since multidimensional radiative transfer is complex, it is assumed that the transport of radiation can be approximated by a quasi-two-dimensional field based on the vertical temperature, water-vapor, and pollutant distributions at several predetermined horizontal positions. The radiative fluxes in the atmosphere are then evaluated at a few prescribed horizontal locations and linear or nonlinear interpolation is then used to determine the radiative fluxes between these locations.

The radiative fluxes and flux divergences are evaluated by dividing the entire electromagnetic spectrum into solar ($0.3 \leqslant \lambda < 4$ μm) and thermal ($4 \leqslant \lambda \leqslant 100$ μm) portions. The computational details can be found in Bergstrom and Viskanta *(1973b)*. Total emissivity data for water vapor and carbon dioxide were used, and scattering was neglected in predicting radiative transfer in the thermal part of the spectrum. It was assumed that the influence of gaseous pollutants could be confined to the 8 to 12 μm spectral region due to the relative opacity of the H_2O and CO_2 bands. Ethylene or sulfur dioxide were considered to be representative pollutants. The spectral absorption and scattering characteristics of the aerosol in a polluted atmosphere were taken from the model developed by Bergstrom *(1972)*.

Numerical Method of Solution

The alternating - direction - implicit (ADI) method *(Roache 1972)* was employed to solve the transport equations [1]. The selection of suitable grid spacing, appropriate finite-difference approximations for the spatial derivatives and the algorithm itself, and tests for convergence are discussed in detail by Johnson *(1975)*. To improve the resolution near the surface, a logarithmic-uniform grid spacing was chosen in the vertical direction. The logarithmic spacing extended to about 1 km from the earth surface, and from there to the top of the PBL (~ 2 km) the spacing was uniform. A uniform spacing was also employed in the horizontal direction and in the soil layer.

The number of grid points and their spacing in the vertical and horizontal directions can be varied. The results reported have been obtained by using 22 nodes in the vertical direction and 17 in the horizontal direction. The first vertical grid point was located at 5 m from the surface and the horizontal grid spacing was 1.5 km. The program required practically the entire high-speed memory capacity (138,000/150,000 bytes octal) of the National Center for Atmospheric Research CDC-7600 digital computer. The computational time was approximately 8 minutes for a 24-hour simulation period.

RESULTS AND DISCUSSION

Numerical Experiments

The numerical model has been tested, and a number of numerical experiments have been performed, using the city of St. Louis as an example. Because of the length and scope of the paper, it is possible to include only some selected results for the temperature in the atmosphere. The experiments were designed to simulate the thermal structure and pollutant dispersion in the urban atmosphere. The urban area was modeled by varying the appropriate surface parameters between rural and urban values in the horizontal direction. The value of these interface parameters are given in table 2. A horizontal distribu-

Table 2.—Numerical values of interface parameters for simulations (Johnson, 1975)

Parameter	Upwind rural	Urban Center
Solar albedo	0.18	0.12
Thermal emittance	.90	.95
Soil thermal conductivity (W/mK)	.1	.5
Soil thermal diffusivity (10^7 m²/s)	1	2.5
Surface roughness (m)	.2	1.0
Moisture availability parameter	.1	.05
Lower soil boundary temperature (K)	295.5	295.5
Urban heat source (W/m²)	2	20
Aerosol pollutant source (μg/m²s)	0	2.5 or 5
Pollutant gas source (μg/m²s)	0	2.5 or 5

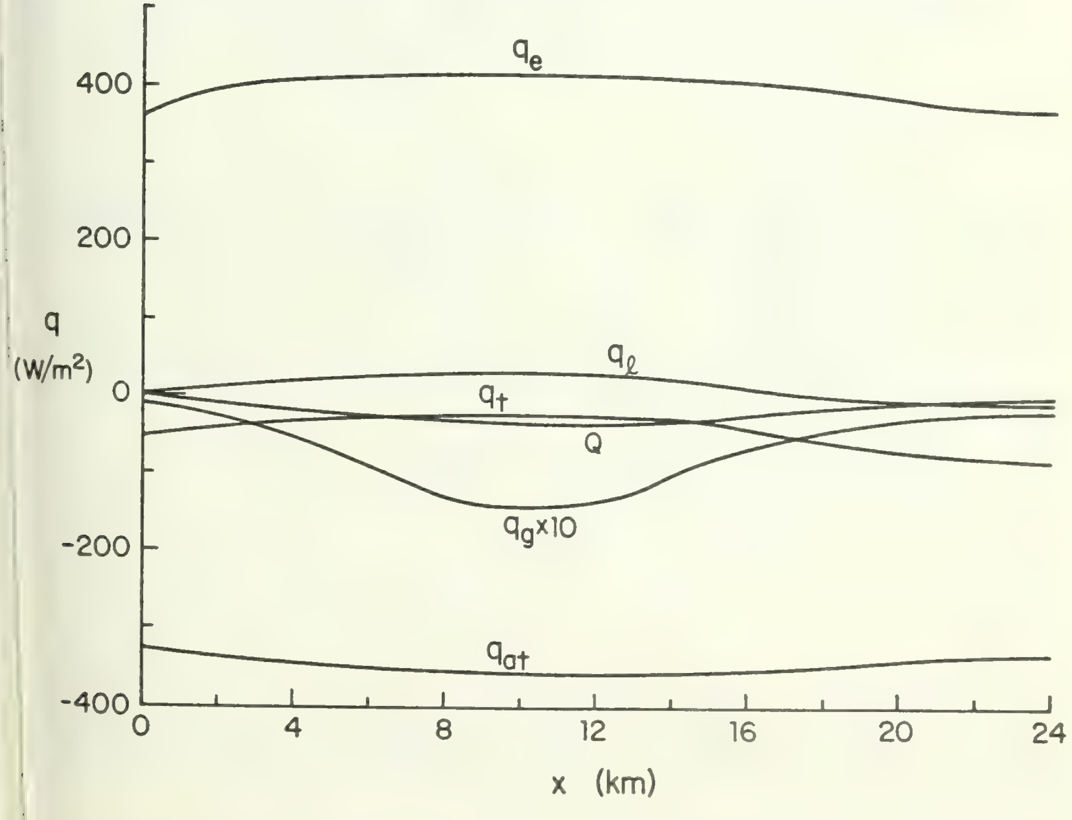
tion was established by selecting the values of parameters at the rural and urban center locations and, for lack of any better data or information, a Gaussian distribution curve was then fitted between the urban and rural locations by specifying the standard deviation of a suitably chosen mean value. The data given in table 2 are representative values over the city.

The simulations were started at 1200 solar time and continued for a 24-hour period. The initial temperature profiles used were taken from Lettau and Davidson *(1957)* for 24 August 1954 and were imposed over the entire area (no x-variation). The initial horizontal and lateral velocity fields were either identical to or decreased by a factor of 2 of those given by Lettau and Davidson for the O'Neill Great Plains Turbulence Study. The pollutant-concentration profiles were initialized to a constant background value of 50 $\mu g/m^3$.

Components of the Energy Budget at the Surface

The surface temperature can be considered as the forcing function of the model. Thus it is important to understand the variation of the energy budget components along the urban area. These are presented in figures 2 and 3 at 2400 of the first day and 1200 of the second day. Inspection of figure 2 shows that the emitted (q_e) and the absorbed thermal (q_{at}) fluxes are the dominant components. The turbulent (q_t), the latent

Figure 2.—Variation of the surface balance flux components (q_t-turbulent, q_l-latent, q_e-emitted, q_{as}-absorbed solar, q_{at}-absorbed thermal, q_g-ground conduction, Q-urban heat source) at the surface at 2400 of the first day; Gaussian distribution, radiatively nonparticipating, u_g=6 m/s and v_g=4 m/s.



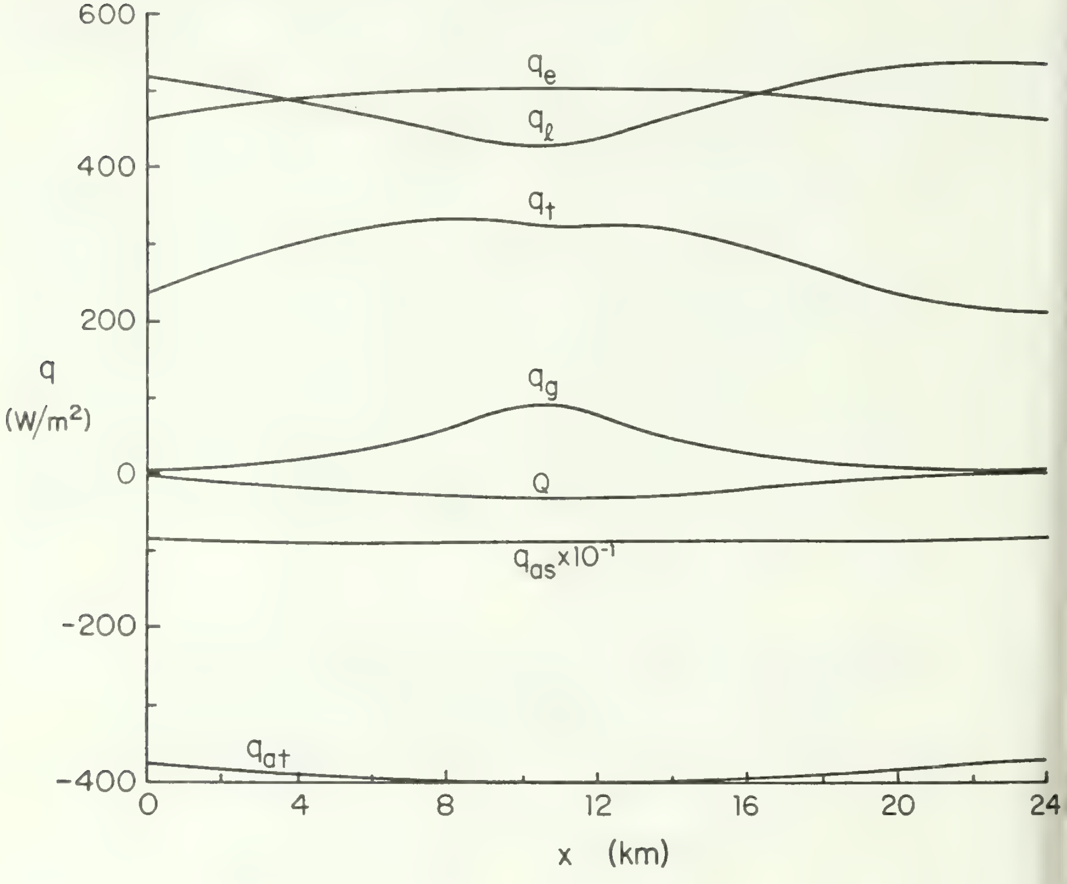


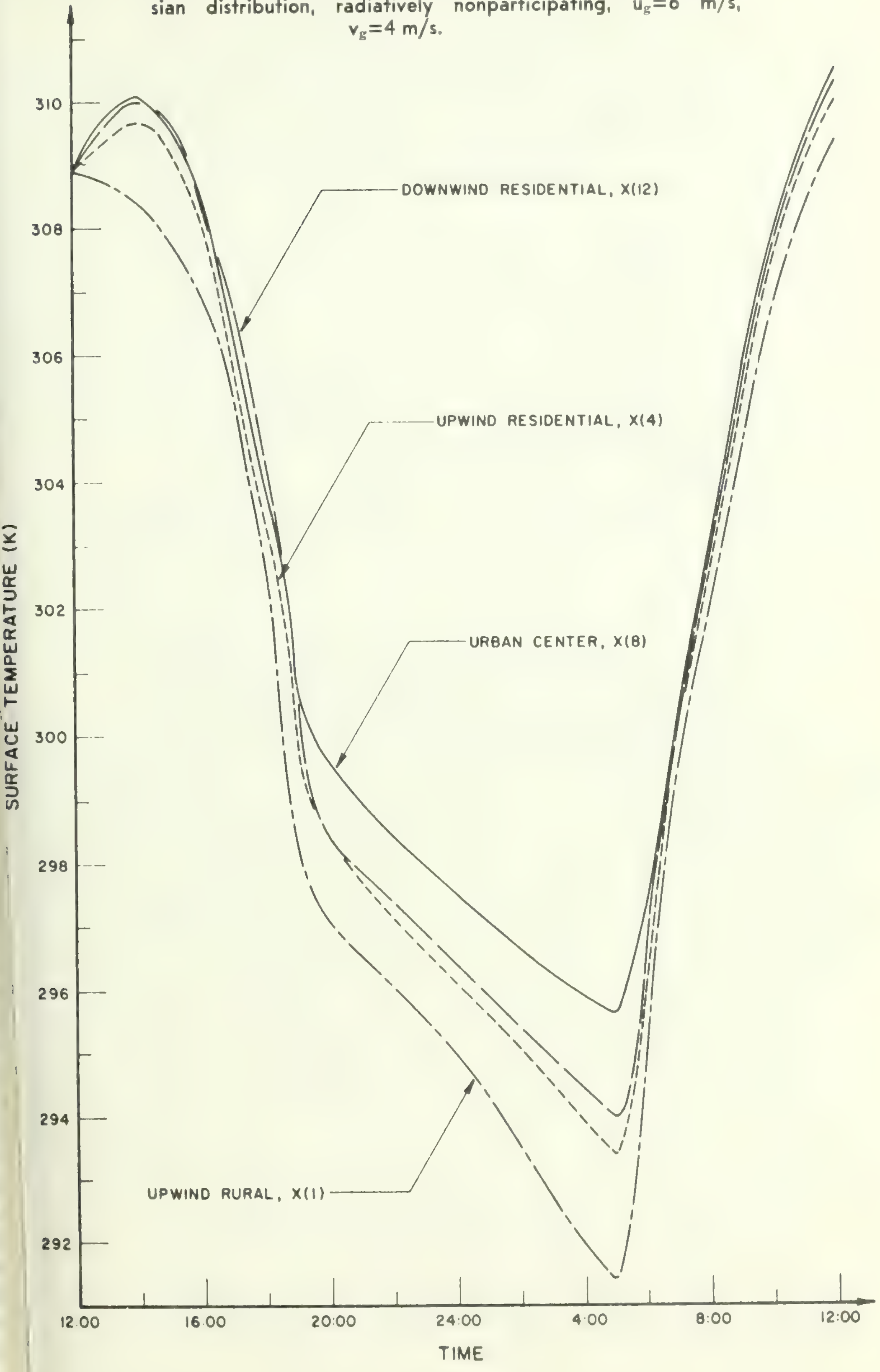
Figure 3.—Variation of surface energy balance flux components at 1200 of the second day; Gaussian distribution, radiatively nonparticipating, $u_g = 6$ m/s and $v_g = 4$ m/s.

(q_l), the ground conduction (q_g), and the man-made urban heat (Q) fluxes are significantly smaller. However, at noon (fig. 3) the absorbed solar flux (q_{as}) is the largest term in the energy balance and the man-made heat source (Q) is the smallest. At the urban center ($x = 10.5$ km) the soil heat conduction term (q_g) amounts to only about 10 percent of the absorbed solar flux. The turbulent (q_t) and the latent (q_l) fluxes are quite sensitive to surface gradients and show significant variation along the urban area.

Surface Temperature

The diurnal variation of the surface temperatures at four positions along the urban area are shown in figure 4. The surface temperature drops sharply in the late afternoon, reaches a minimum just before sunrise (between 0500 and 0600), and rises sharply in the morning. During the first few hours of the simulation, an initial transient is noted in the surface temperature. This is due to the fact that the assumed initial velocity, temperature, and water-vapor concentration profiles were far away from the quasi-steady solution induced by the diurnal cycle, and it took about 2 to 3 hours for the system to adjust. The surface temperatures at the downwind residential location (node 12) are slightly higher than at the upwind residential (node 4) locations. This is attributed to the heating of the air as it flows over the warm city. The maximum surface

Figure 4.—Variation of surface temperature with time; Gaussian distribution, radiatively nonparticipating, $u_g=6$ m/s, $v_g=4$ m/s.



temperature difference (about 4°C) between the urban center and upwind rural locations occurs just before sunrise. On the other hand, for a simulation with higher wind speeds ($u_g = 12$ m/s and $v_g = 8$ m/s), the maximum difference occurs in the evening at 1900 and remains almost constant throughout the night *(Johnson 1975)*.

The effect of radiatively participating pollutants as measured by a local surface-temperature difference (temperature with participating pollutants/temperature without) is illustrated in figure 5. The temperature differences result from an interaction between many complex phenomena, and therefore individual influences are not easily identified. The surface temperature difference is largest during the night and reaches a maximum before sunrise 0500 and is smallest at noon. The differences between the surface temperatures are considerably smaller for higher wind speeds *(Johnson 1975)*.

A comparison of the surface temperatures for the Gaussian and rectangular distributions of urban man-made heat sources is illustrated in figure 6. The results show that the difference between the two results is only about 1°C, and the maximum occurs early in the morning (0500) when the man-made urban heat source is a significant component of the energy budget. At noon (1200) the surface temperatures in the city differ by only about 0.1°C, indicating the predominance of the radiant energy transfer in the interfacial energy balance.

Temperature Structure

The isopleths of the two-dimensional potential temperature fields at 6-hour

Figure 5.—Local surface temperature difference (simulation with radiatively participating pollutants minus simulation with radiatively nonparticipating pollutants) along the city; Gaussian distribution, ethylene (C_2H_4)-pollutant gas, $u_g=6$ m/s, $v_g=4$ m/s, $m_1=m_2=2.5$ $\mu g/m^2s$.

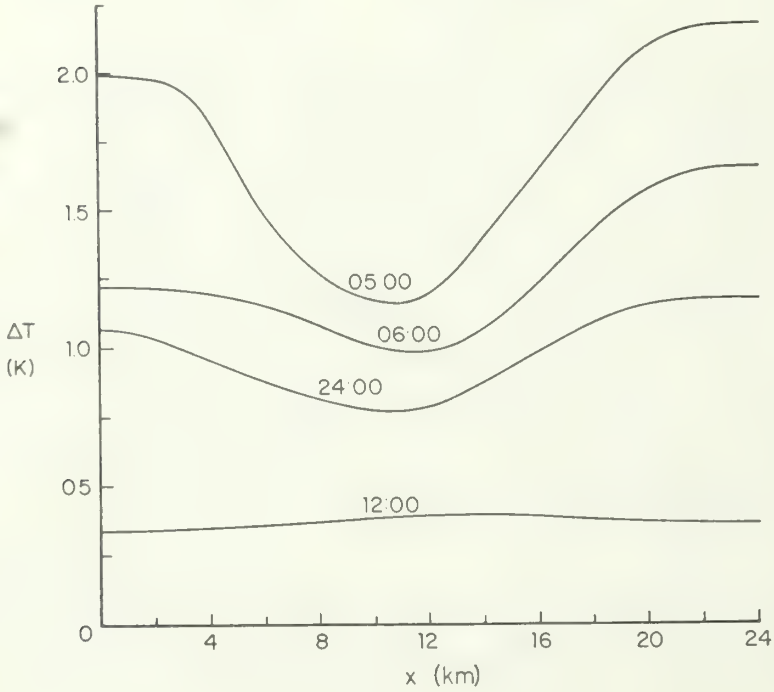
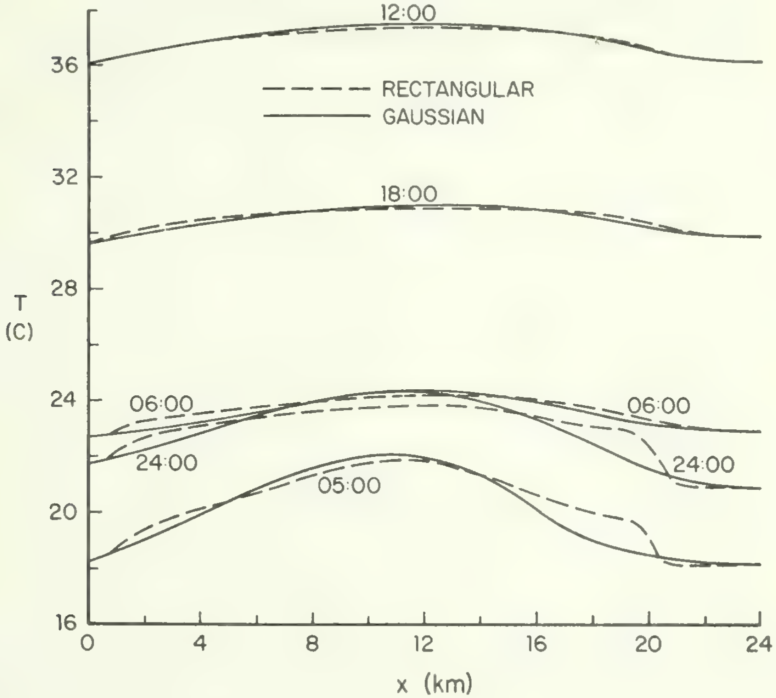


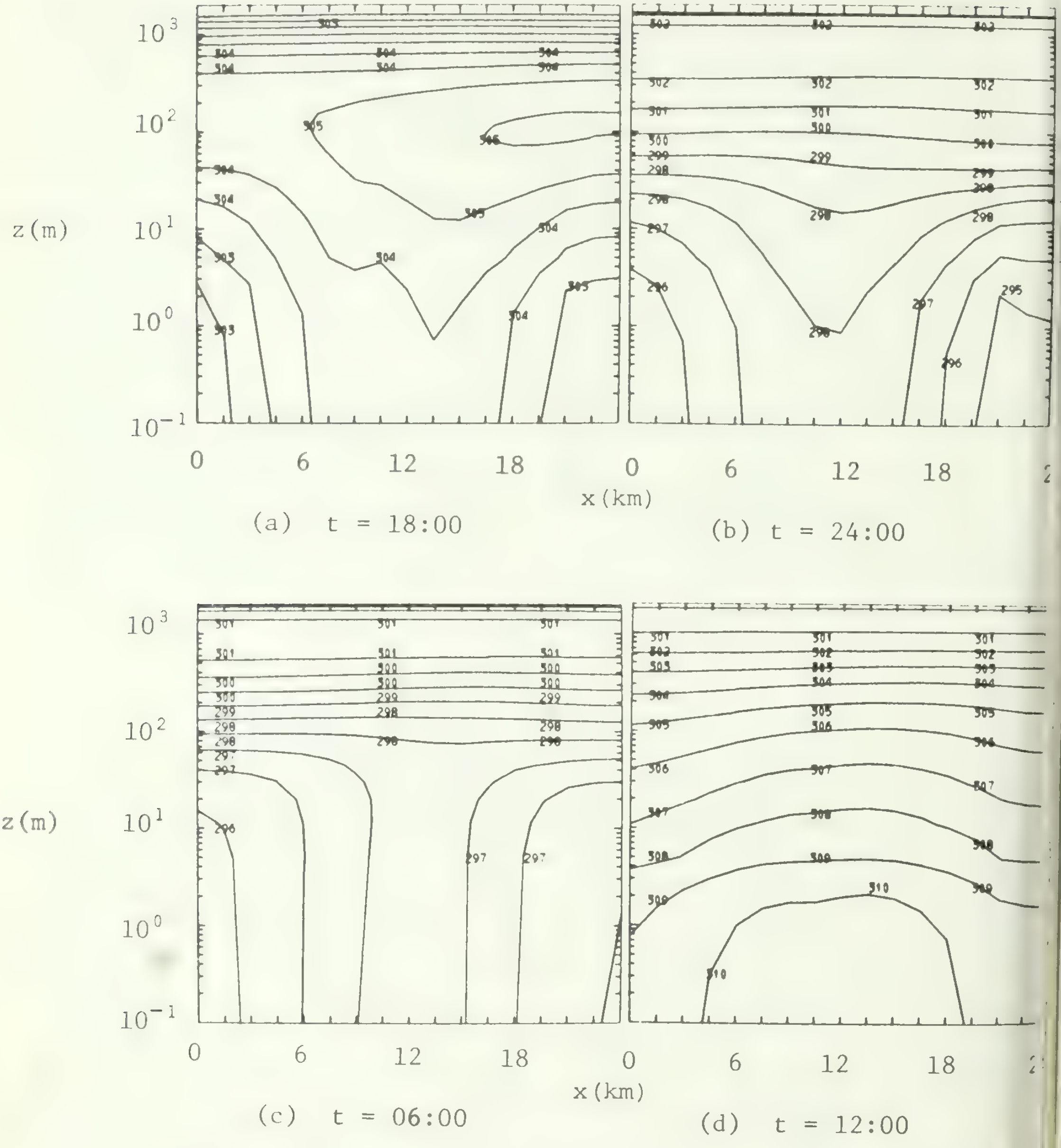
Figure 6.—Comparison of surface temperatures for Gaussian and rectangular distributions of urban heat and pollutant sources; radiatively participating, ethylene (C_2H_4)-pollutant gas, $u_g = 6$ m/s, $v_g = 4$ m/s, $m_1 = m_2 = 2.5\ \mu g/m^2s$.



intervals for a simulation with radiatively nonparticipating pollutants are shown in figure 7. At 1800 the atmosphere is nearly adiabatic, especially in the upwind rural area, with a thermal plume having a temperature of about 305 K forming at a height of about 100 m downwind of the city center (node 8, x = 10.5 km). Note that the last digit denoting the temperature of the isoherm at 1800, 2400, and 0600 hours has been truncated. However, the plume is not felt downwind, and the upwind and downwind surface temperatures are nearly identical. A surface temperature nversion develops at night and is seen o be deeper over the rural area than ver the city. This is indicative of the octurnal heat island, which decreases he stability of the atmosphere. The magnitude of this heat island is larger t night than during the day. This type f behavior is well documented *(Peterson 1969, Oke 1973b)*. Just after sunrise (0600) the breakup of the stable layer was noted. The surface inversion breaks up rapidly after sunrise due to heating of the surface by absorption of solar radiation, and by 0900 all traces of the inversion have disappeared. Similar types of diurnal variation of thermal structure have been found for other simulations under different conditions *(Johnson 1975)*.

The maximum temperature difference between simulations with radiatively participating and nonparticipatng pollutants occurs at the urban center late at night (fig. 8). The temperature differences are seen to be largest near the surface and are confined to the lowest 600 meters of the PBL. When the pollutant gas is assumed to have the radiative properties of sulfur dioxide (SO_2), the temperature structure predicted is practically the same as that for the

Figure 7.—Isopleths of potential temperature (in K); Gaussian distribution, radiatively nonparticipating, $u_g = 6$ m/s, $v_g = 4$ m/s.



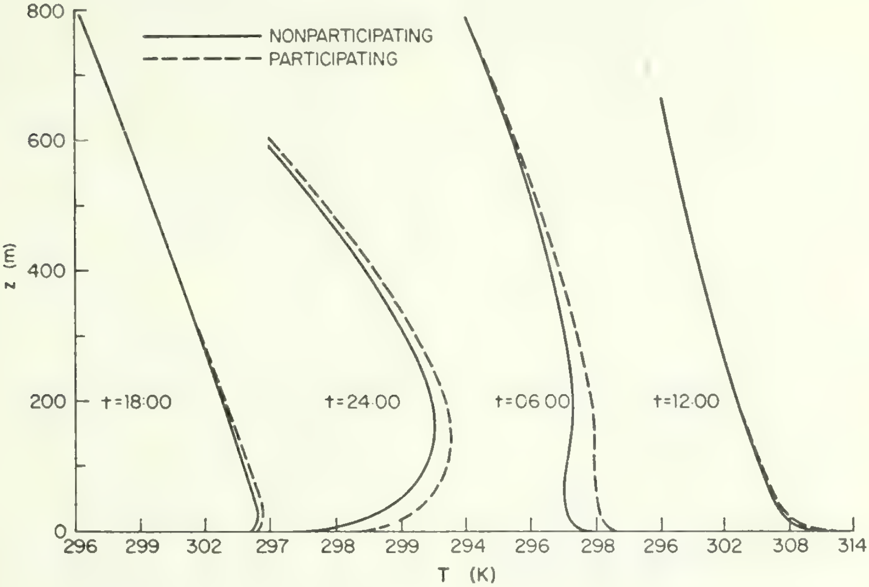
(a) t = 18:00

(b) t = 24:00

(c) t = 06:00

(d) t = 12:00

Figure 8.—Comparison of thermodynamic temperatures at the urban center; Gaussian distribution, ethylene (C_2H_4)-pollutant gas, $u_g=6$ m/s, $v_g=4$ m/s, $m_1=m_2=2.5$ $\mu g/m^2s$.



radiatively nonparticipating pollutant gas. This is due to the fact that SO_2 is a weakly radiating gas. The results are consistent with those obtained with the one-dimensional model *(Bergstrom and Viskanta 1973a)*. The net effect of the city and the human activity on the temperature distribution is illustrated in figure 9. The results show that the presence of radatively participating polutants dampens the amplitude of the diurnal temperature variations and that or a relatively short (24-hour) simulation the effects are confined primarily below 600 m.

Urban Heat Island

The urban heat island is a well-known nd accepted fact *(Peterson 1969, Oke 973b)*. The urban heat-island itensity maximum difference between upwind ural and highest urban surface temprature, Δt_{u-r}) predicted is shown in gure 10. For the assumed Gaussian istribution of man-made heat sources, he maximum surface temperature diference occurred at the urban center, whereas for the rectangular distribution during the night it occurred downwind of the center. The results presented in the figure show that there is a double peak in ΔT_{u-r}. The first peak is noted at about 2000. It arises due to the more rapid cooling at the upwind rural area than in the city. The maximum heat-island intensity occurs just before sunrise and has a magnitude of about 4°C. For the population of the urban area and wind speeds of the simulation this value is in good agreement with the observations and empirical correlation of Oke *(1973b)*. For a simulation with lower wind speeds ($u_g \simeq 2.4$ m/s and $v_g \simeq 1.6$ m/s), which are not reported here, the maximum heat-island intensity reached about 10°C. This is also in good agreement with the nighttime and daytime observed temperature excesses between the urban and rural locations *(Oke 1973b, DeMarrais 1975)*.

CONCLUSIONS

As a result of a limited number of numerical simulations that have been

Figure 9.—Comparison of perturbation potential temperatures (temperature in the city minus the temperature at the upwind rural location) at the urban center for radiatively nonparticipating (a) and radiatively participating (b) simulations; Gaussian distribution, ethylene (C_2H_4)-pollutant gas, $u_g=6$ m/s, $v_g=4$ m/s, $m_1=m_2=2.5$ μg/m²s.

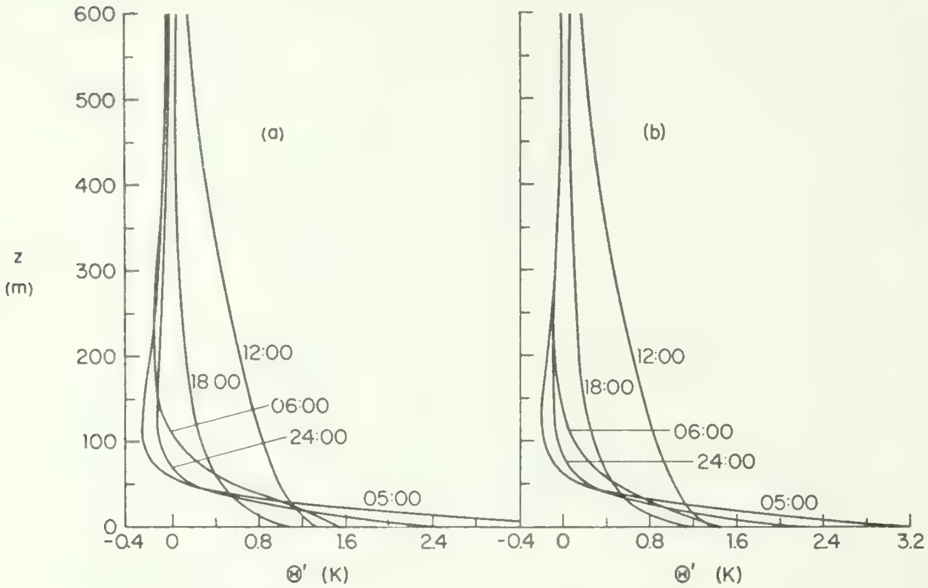
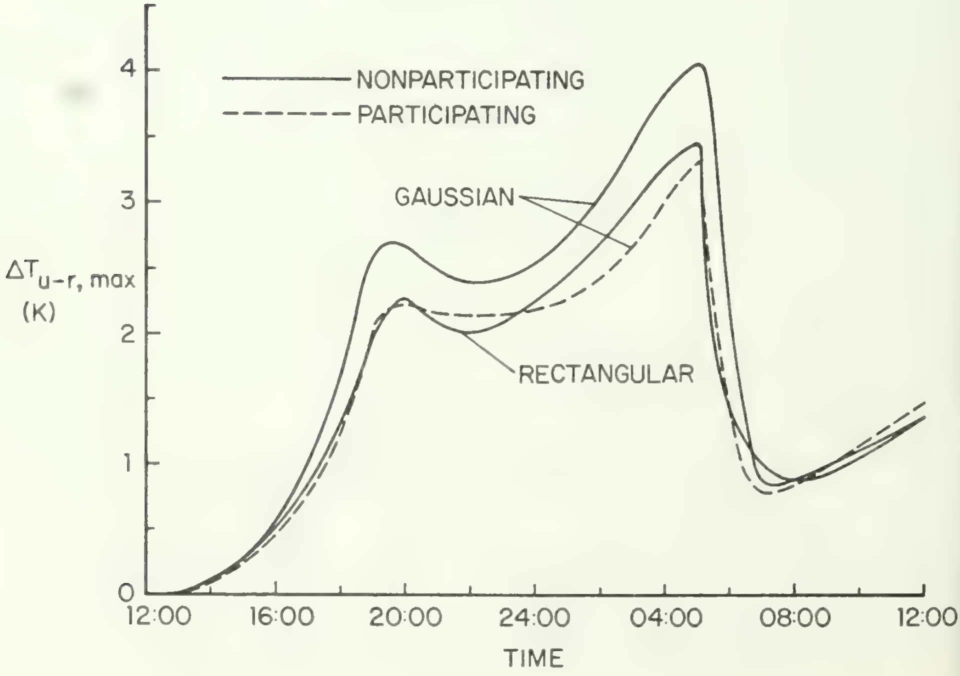


Figure 10.—Comparison of maximum urban upwind rural surface temperature differences; ethylene (C_2H_4)-pollutant gas, $u_g=6$ m/s, $v_g=4$ m/s, $m_1=m_2=2.5$ μg/m²s.



performed for selected meteorological conditions during the summer, the following generalizations can be made:

1. The unsteady two-dimensional transport model predicts an urban heat-island intensity that is sensitive to wind speed and latent energy transport through Halstead's moisture parameter. The intensity of the urban heat island reached a magnitude of about 4°C near sunrise and about 1.4°C at noon.
2. For the conditions studied, the radiatively participating pollutants are relatively unimportant in forming the urban heat island compared to other factors. During the night, air pollution does increase the surface temperature by about 1.25°C at the urban center.
3. The role of radiatively participating pollutants in the formation of the thermal structure is relatively small and it is greatest late at night. The largest effect of pollutants was to decrease the stability at night and hence increase turbulent transport near the surface particularly at heights below 500 m.
4. The feedback mechanism between pollution, thermal structure, stability, and dispersion has the potential of being significant in modifying pollutant concentrations under more stable conditions and higher pollutant loadings. However, the magnitudes of the changes are dependent on the coupling between the radiative properties of air pollution and the buoyancy-enhanced turbulence. Due to the uncertainties involved in predicting either of these two quantities, the magnitude of these changes is uncertain.

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A Preliminary Investigation of the Nocturnal Temperature Structure above the City of Edmonton, Alberta

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ABSTRACT.—Information about the nocturnal temperature structure over Edmonton, Alberta. Observations of the temperature fields, including two- and three-dimensional forms of the nocturnal heat island, were obtained from minisonde ascents, an instrumented helicopter, and towers during a 3-week urban air-pollution field study. Results show that urban-induced temperature modification is typically in the lowest 100 m above ground. Along the direction of the prevailing wind, there is a progressive modification of very stable upwind air as it flows toward the city center, the urban air being less stable. Implications of these observed features on urban air pollutants are discussed.

THE NOCTURNAL TEMPERATURE in the lowest few hundred meters above urban areas has received much attention in recent years *(Oke 1974, Garstang et al. 1975)*. Observations have shown that the city's influence on the nocturnal temperature regime commonly can extend up to 300 m and that thermal boundary layers are generated as stable upwind rural air is advected over a warm urban surface. This sometimes results in a well-defined rban thermal and pollution plume ex-ending aloft and downwind of the city. Within the modified urban air, tempera-ure profiles often exhibit near-neutral onditions, thereby supporting the con-ention of a well-mixed urban layer. ccordingly, there is usually a marked ecrease in frequency and intensity of round-based inversions over urban reas compared to those over adjacent ural surroundings.

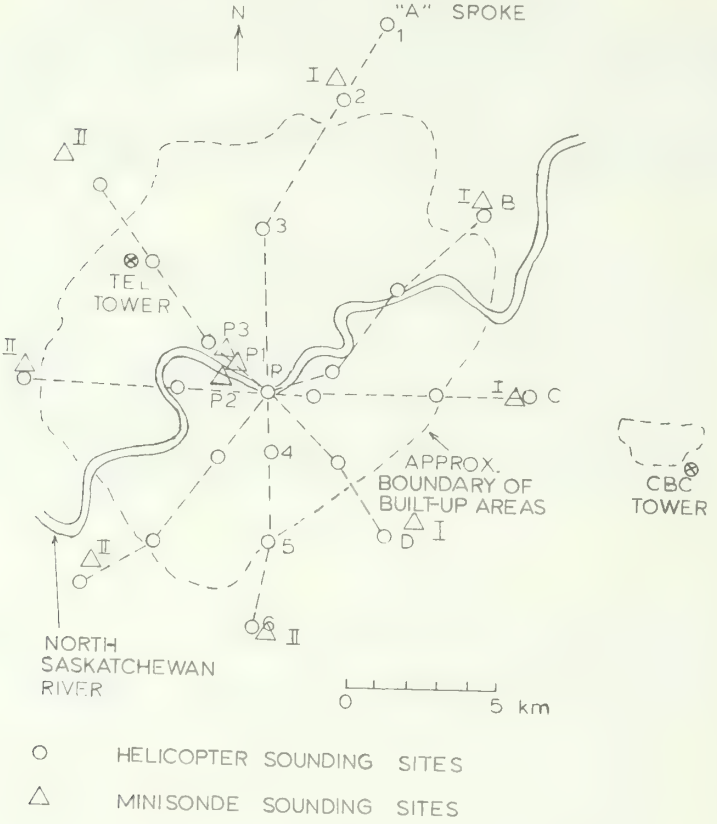
The development of this modified ayer above the city is generally attrib-uted to any one or a combination of the ollowing processes: (1) thermal turbu-lence due to anthropogenic sources or to the release of stored heat in urban structures, (2) mechanical turbulence enerated by air flow over urban roughness elements and subsequent redistribution of heat, and (3) radiative processes in the urban atmosphere.

The purpose of this paper is to present some qualitive and quantitative aspects (including spatial characteristics) of the nocturnal temperature regime and associated boundary layer structure over Edmonton, Alberta. The implications for urban air-pollution modelling are also discussed. The study is based primarily on low-level temperature-profile measurements obtained in and near Edmonton during an intensive 3-week urban-air-pollution field study in November and December 1974.

EXPERIMENTAL SITE AND PROCEDURE

Edmonton, a medium-size city with a population of about 0.5 million, was selected as the target for this urban meteorological and pollution study. The city is located on the banks of the North Saskatchewan River in Central Alberta (53°33′N,113°30′W). The topography is generally flat except near the river valley, which runs in an approximately northeast-southwest line through the city (fig. 1). There the valley is steep-sided and narrow, with an average

Figure 1.—Map of the Edmonton area and sampling scheme for probing the urban atmosphere.



depth of about 50 m. From the river banks, the land rises gradually, the most significant change being to the southeast (a slope of 1:200 at 15 km from the city center). The extent of the built-up area is shown in figure 1. The urban core consists primarily of medium-density structures. This is surrounded by mixed low-density commercial and residential areas. Heavy industries are mostly on the eastern fringes of the built-up areas.

The synoptic-meteorological conditions during the investigation period (19 November to 5 December 1974) were near normal for this time of the year, with one notable exception: a lack of significant snow cover in the region. Otherwise typical winter characteristics prevailed. This period was chosen in part to maximize the chances of observing well-developed heat-island effects and high air-pollution episodes.

For the monitoring of low-level temperature profiles, two mobile minisond systems, a helicopter, and two instrumented towers were used. The minisonde system is a lightweight version o the radiosonde. It consists of a smal inexpensive fast-response temperatur sonde (microbead thermistor, time constant 1.5 s, relative accuracy 0.2° C) which is carried aloft by a standar pilot balloon with a rise rate of abou 3 m/s. Heights and winds aloft wer obtained by tracking the balloon via the double-theodolite method. The helicopter was equipped with a Sign-X temperature unit, along with pollution-measuring equipment. The temperature sensor for this unit consisted of a shielded thermistor with a response time of about 0.5 s and a relative accuracy of 0.2°C. Heights were obtained from a pressure transducer with a similar response time and a relative accuracy of 5 m.

Supplementary temperature information was obtained from two instrumented towers (fig. 1) operated by the Atmospheric Environment Service, Canada. Both the telephone and CBC towers (urban and rural respectively) are equipped with Rosemount platinum resistance thermometers in aspirated radiation shields and with linear matching bridges at heights of 10.0 and 91.5 m above ground. An additional temperature sensor is located at the 45.7-m level in the urban tower. Wind measurements on both towers were recorded at the 91.5-m level.

The adopted sampling scheme for probing the urban atmosphere is also shown in figure 1. Nocturnal measurements, utilizing the minisonde system, consisted of comparative urban and upwind rural temperature profiles during the periods shortly after sunset and before sunrise. Eleven simultaneous comparisons were obtained. One minisonde unit was used at a fixed location near the city center (P1, P2, or P3) depending on the prevailing wind. Simultaneously, the second unit monitored the nearby upwind rural profile at locations A, B, C, or D (I or II), also depending on the prevailing wind.

On two occasions, 12 minisonde ascents were made along two transects across the city, one line perpendicular to the other, to investigate the spatial structure of the boundary layer. At selected points along the spokes A, B, C, or D, helicopter soundings near sunrise provided vertical profiles of temperature upwind, over, and downwind of the urban area. In addition, the instrumented towers gave continuous nocturnal measurements of low-level urban and rural temperature gradients during the entire study period.

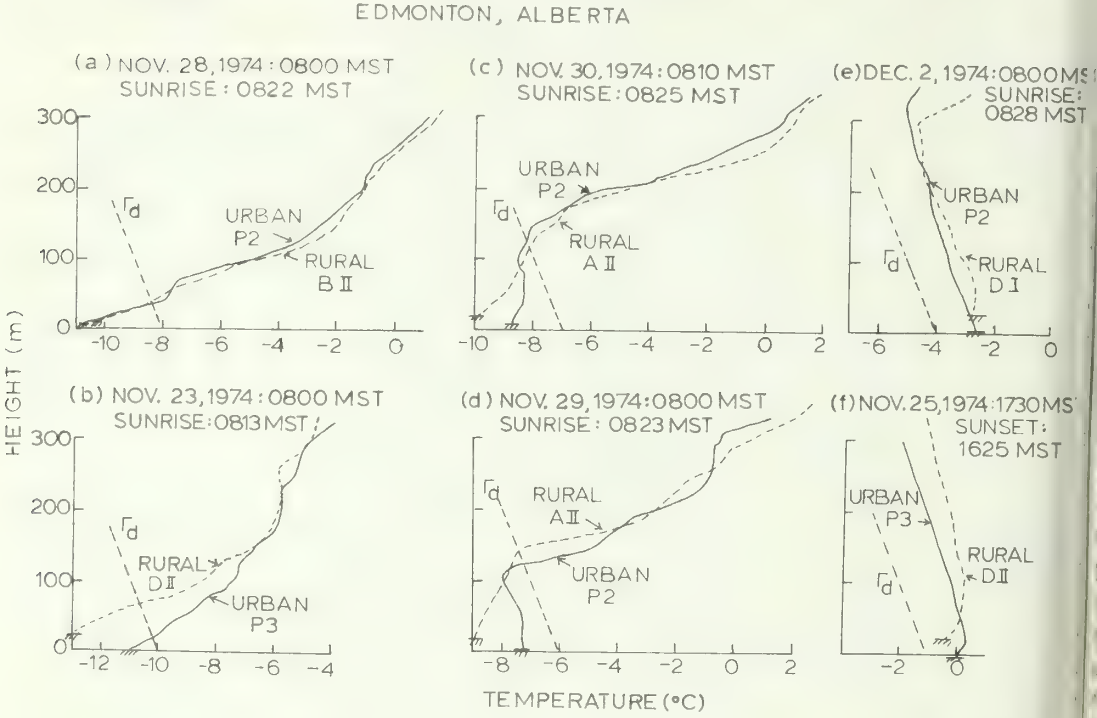
URBAN AND UPWIND RURAL TEMPERATURE PROFILES

Typical examples of comparative urban and upwind rural nocturnal temperature profiles, based on minisonde ascents, are shown in figure 2. These were selected primarily to illustrate the wide range in urban atmospheric temperature profiles than can occur under inversion conditions in the nearby upwind rural areas.

In figure 2(a), the prevailing wind was from the southwest with speeds below 4.0 m/s in the lowest 100 m. Despite the lack of significant snow cover in the area, intense and deep surface-based inversions (6.9°C/100 m in the low-levels, inversion top at 430 m) occurred at both urban and rural sounding sites. As no urban-induced temperature effects are discernable, it is not possible to define a mixed or modified layer. This suggests that radiative cooling over the southwestern areas of the city was at least as intense as that over the nearby rural surroundings. In this sector of the city, larger segments of green areas than urbanized land occur. It was noted, however, that similar urban and rural inversion profiles occurred on occasions with westerly winds.

The situation, illustrated in figure 2(b), is for a northwest wind. Typical wind speeds were less than 2.5 m/s below 100 m, and less than 5.0 m/s in the layer between 100 and 200 m. The upwind rural inversion was both intense and deep. The air trajectory was mainly over built-up areas as it approached the urban site. A significant heat island, decreasing with height, was evident. Noteworthy, however, was the fact that the modified urban layer, about 140 m deep, remained strongly stable (3.2°C/100 m inversion), although slightly weakened

Figure 2.—Examples of simultaneous urban and upwind rural temperature profiles from the minisonde systems for the period between sunset and sunrise.



in comparison to that in the rural environment. This type of effect was observed on several nights. The dominance of radiative processes over the relatively low-density urban structures would perhaps explain this type of urban profile.

Another situation that occurred commonly is shown in figure 2(c). Here, the upwind rural site was characterized by a ground-based inversion, more intense aloft than near the ground. Winds were from the south, and speeds were less than 0.5 m/s below 20 m, increasing to about 4.5 m/s in the layer 20 to 100 m. At the urban site, the profile is near isothermal below 100 m. This type of modification may also be ascribed to radiation processes as suggested by Hage and Longley *(1970)*, in which the city experiences less radiative heat loss than the surrounding countryside. Radiation equilibrium (isothermal) conditions would thus be expected with increasing urban heat-island intensities.

As in the previous example, figur 2(d) shows similar upwind rural conditions with a southerly flow. Win speeds, however, were much stronger 4 to 5 m/s below 50 m, and about 10. m/s between 50 and 100 m. A well-defined mixing layer (about 100 m deep) with near adiabatic conditions, developed over the urban site. This type o urban profile has been observed often i mid-latitude cities *(Clarke and McElro 1974)* and supports Summers *(1967* concept of the city acting as a hea source to create its own mixed laye characterized by an adiabatic lapse rat In this particular example, mechanic turbulence, thermal turbulence, an radiative factors probably all contributed to the modification process.

Figure 2(e), a situation for southea winds, indicates considerable modification below 300 m at both urban a rural sites. Wind speeds ranged fro 3 to 6 m/s in the lowest 50 m. Betwe

50 and 100 m, speeds increased to about 10 m/s and for the subsequent 200 m aloft, averaged about 13 m/s. Lapse rates below the inversion were near adiabatic. As the modification occurred both inside and outside the city, the dominant influence is considered to be of meso-scale extent. The presence of extensive cloud cover on this morning would appear to support this. The slight increase in mixing depth over the city may have been caused by additional mechanical turbulence over urban roughness elements.

Last, figure 2(f) illustrates an ex-mple of conditions after sunset for a orthwest wind. Shallow ground-based nversions at both urban and rural sites vere evident, despite the fact that wind peeds averaged about 7.0 m/s in the owest 50 m depth. There was, in addi-ion, a small heat-island effect. The ur-an inversion was slightly weaker in tensity than that over the rural site.

These examples offer some insight to the problems of defining or predict-g the nocturnal urban boundary layer. the past, this layer, expressed in the rm of an urban mixing layer, has ten incorporated in air-quality disper-on models. The recent works of Clarke d McElroy *(1974)* and DeMarrais *975)* suggest that the depth of the cturnal boundary layer over the center the city can be estimated from the t nperature structure of the upwind r ral environs or by the dry adiabatic e tension of the maximum heat-island t nperature to an upwind rural tem-p rature profile.

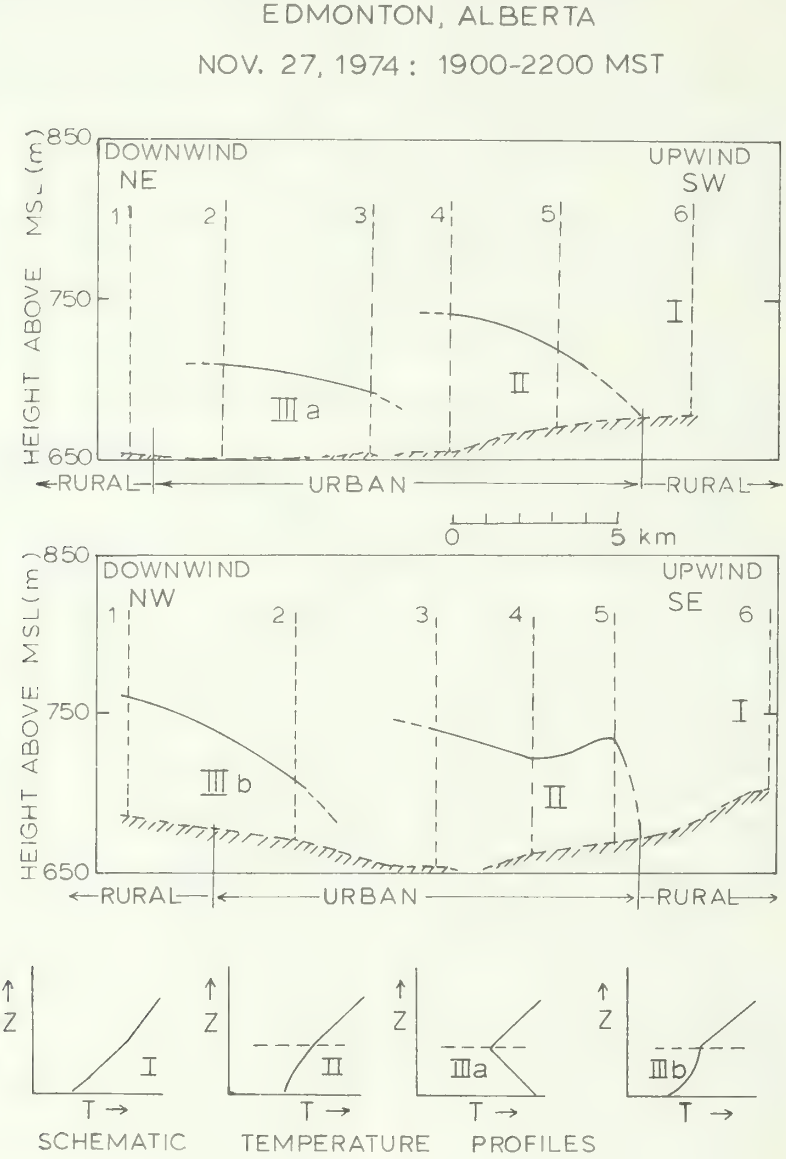
Such techniques unfortunately do not sem suitable for the situation observed in Edmonton, where a near-adiabatic asumption may often be inapplicable. Ireed, the concept of a nocturnal urban ming depth, with the important im-plation of a more or less uniform verti-ca distribution of pollution, would pehaps be more aptly replaced by the te n 'modified depth', in which the ur-ba lapse rate can range from inversion to adiabatic and in which pollution can be stratified. Land-use patterns and associated radiative processes, as well as mechanical and thermal turbulence effects, could then be combined with information on the upwind rural temperature profile to formulate a scheme to predict this modified depth (including its nonoccurrence). The use of a modified depth to define the nocturnal urban boundary layer thickness over Edmonton yields values typically of about 100 m or less near the city center. This corresponds to a boundary layer slope of 1:50 or shallower.

NOCTURNAL URBAN BOUNDARY LAYER STRUCTURE

Spatial aspects of the boundary layer structure over Edmonton were investigated on two nights, 27 November (1900-2200 MST) and 30 November (0500-0810 MST). On both occasions, minisonde ascents were made along two transects, perpendicular to each other, across the city. These low-level profiles were then used to estimate the thickness of the modified depth and the shape and structure of the urban boundary layer. The height of the modified depth was identified as that point on the temperature profile (a continuous temperature trace output) above which the gradient approximately coincided with that of the upwind rural profile or, in some instances, the point where a distinct change in gradient on the urban profile could be readily identified.

Figure 3 shows the boundary layer structure for 27 November along with schematics of the observed temperature profiles. Southerly winds prevailed during this experiment, with mean speeds of about 2.5 m/s below 50 m and 5.5 m/s between 50 and 100 m. The two transects, northeast-to-southwest and northwest-to-southeast, closely followed spokes B and D, respectively (fig. 1). The upwind rural area was denoted region I. Here similar ground-based inversions occurred, both southeast and southwest

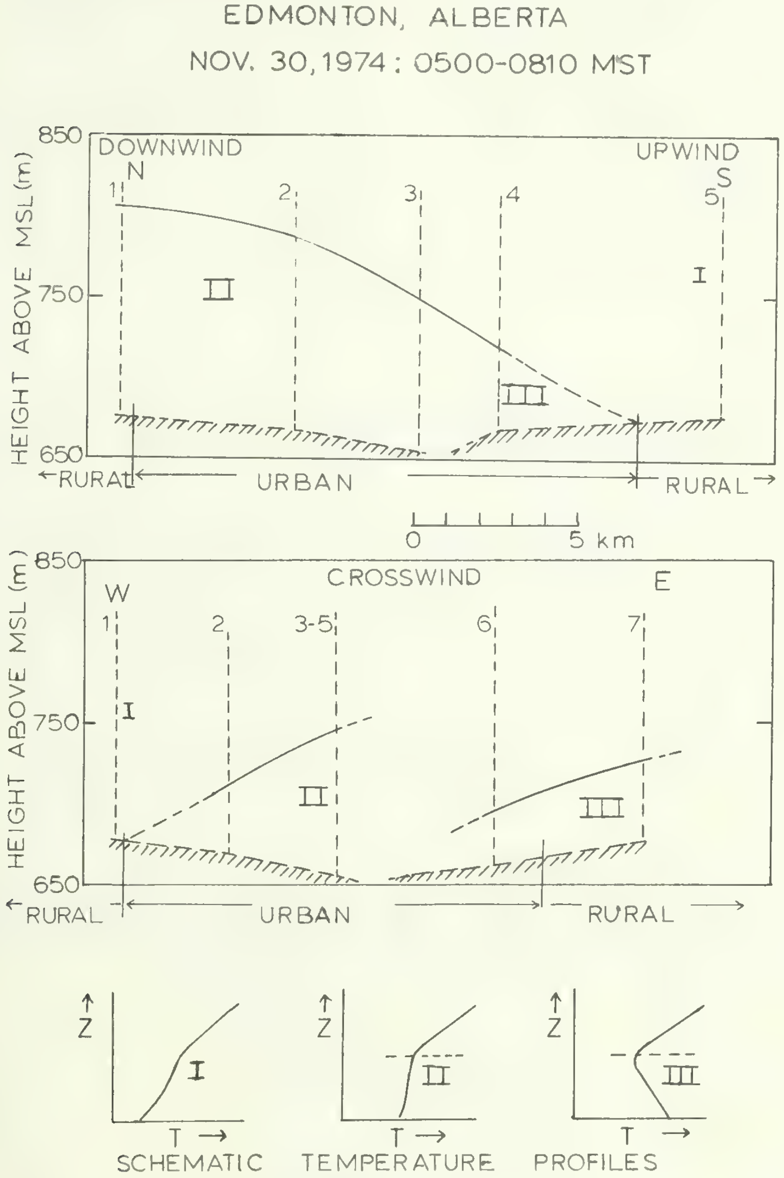
Figure 3.—The nocturnal boundary layer structure over Edmonton on the late evening of 27 November 1974.



of the city center. The characteristic temperature profile of this region was assumed to extend to the edge of the upwind built-up areas. As the air flowed across urbanized land, region II developed, consisting of a modified layer of less intense inversions and a general progressive increase in boundary layer thickness towards the urban center. Further downwind, a second boundary layer could be identified (designate regions, IIIa and IIIb). Here, lapse rat in the modified layer was extremely un stable (superadiabatic) to the north east, whereas it was relatively stabl and of distinct shape to the northwest Boundary-layer depth on this night ove the city was confined to the lowes 100 m.

The second experiment (fig. 4) showe

Figure 4.—Along-wind and cross-wind structures of the nocturnal boundary layer over Edmonton on the early morning of 30 November 1974.



the structure on the early morning of 30 November. The two transects, north-south and east-west, closely followed spokes A and C respectively (fig. 1). The air flow was again from the south. Wind speeds below 20 m were light, about 1.0 m/s, increasing to about 4.5 m/s in the layer 20 to 100 m. Along the direction of the wind, an increasing boundary layer could be identified from the upwind south side across to the downwind side of the city. In this layer of modified air, temperature profiles decreased in stability from near adiabatic upwind to slightly stable downwind of the city center. Crosswind, the boundary layer structure closely resembled that which was observed on 27

November (fig. 3). These examples of the spatial nature of the nocturnal urban boundary layer over Edmonton are believed to reflect the heteorogenous nature of the urban surfaces.

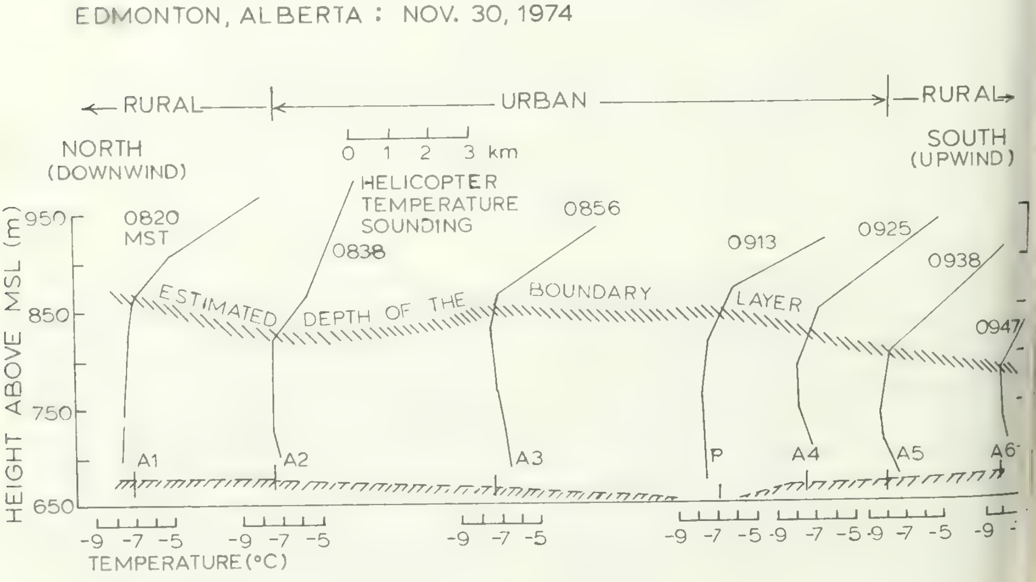
URBAN BOUNDARY LAYER STRUCTURE NEAR SUNRISE

Observations of the boundary-layer structure over Edmonton from detailed helicopter temperature profiles were made only during daylight hours because of restriction on night-time flying. Hence, for this study, only the measurements near sunrise were considered relevant. These provided information on the temporal evolution of the nocturnal boundary layer through the sunrise transition period.

The example (fig. 5) was obtained on the morning of 30 November (0800-1000 MST) along spoke A (fig. 1). It depicts the temperature structure upwind of, over, and downwind of the urban area, along with the associated boundary layer, and, in addition, it represents the evolution of the nocturnal boundary layer (fig. 4) through the sunrise transition period. Wind direction and speed remained almost the same as previousl given for the period 0500-0810 MST.

The most significant change in boundary-layer shape and depth occurred ove the upwind rural areas. Here the nocturnal ground-based inversions wer destroyed up to a depth of about 120 m through natural convection processe within an hour and a half after sunris This effect was observed on most late morning temperature soundings fro both the minisonde and helicopter measurements. In general, the effect of sola radiation and subsequent warming fro below created significant daytime rur mixing depths of almost similar magnitude to that over the urban areas b mid-day. The structure below the boundary layer closely followed that observ before sunrise (fig. 5). Profiles generally decreased in stability along th direction of the prevailing wind, fro near adiabatic upwind to slightly stab on the downwind side of the city.

Figure 5.—Helicopter temperature profiles across Edmonton in the direction of the prevailing wind at and after sunrise on 30 November 1974. The inferred shape and depth of the boundary layer are also indicated.



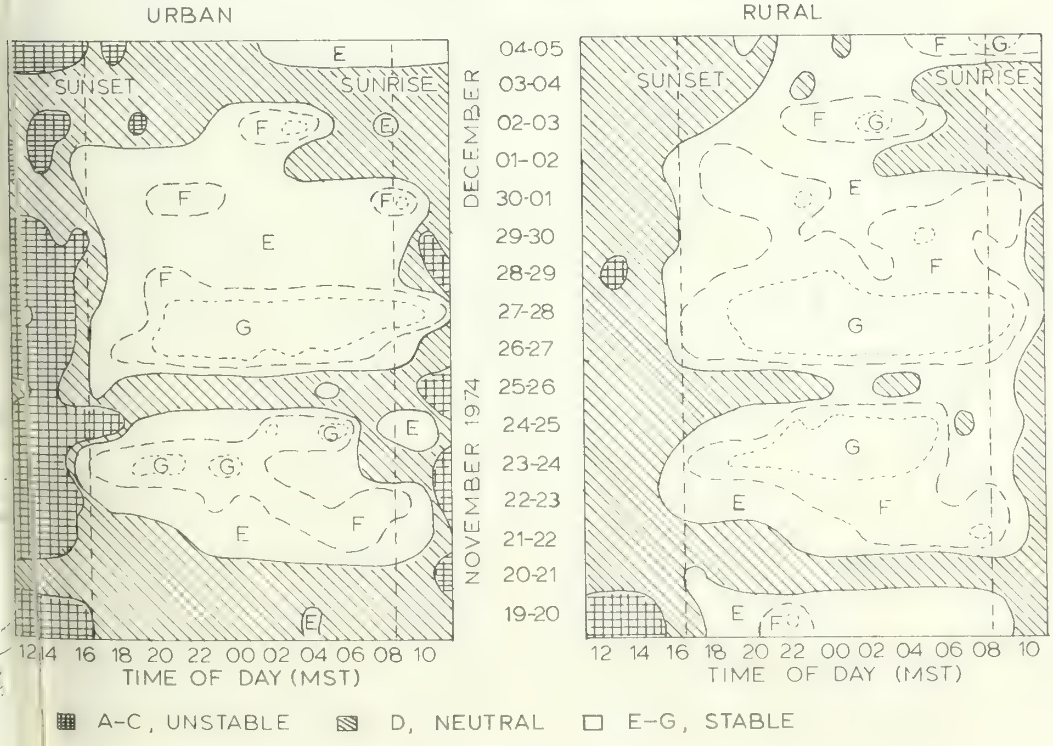
URBAN AND RURAL TOWER STABILITIES

The hourly vertical temperature gradiants, monitored between 10.0 and 91.5 m on the urban and rural towers during the period 19 November to 5 December 1974, were used to approximate low-level stabilities in and near Edmonton. Initially, the gradients were examined in terms of Pasquill stability categories as defined by USAEC (1972) (table 1). The stability patterns are illustrated in figure 6. Between sunset and sunrise, both urban and rural towers showed a prevalence of stable conditions (63 and 78 percent respectively). An examination of these nocturnal stability patterns indicates that, relative to the rural environs, the urban site is characterized by no change in stability 56 percent of the time, decreased stability 42 percent, and increased stability 2 percent. Of the cases with decreased stabilities, a change by one stability category (D to C, E to

Table 1.—Classification of atmospheric stability

Stability classification	Pasquill categories	Temperature change with height (°C/100 m)
Extremely unstable	A	< —1.9
Moderately unstable	B	—1.9 to —1.7
Slightly unstable	C	—1.7 to —1.5
Neutral	D	—1.5 to —0.5
Slightly stable	E	—0.5 to 1.5
Moderately stable	F	1.5 to 4.0
Extremely stable	G	> 4.0

Figure 6.—Urban and rural tower stabilities (temperature gradients) in Edmonton during the period 19 November to 5 December 1974.



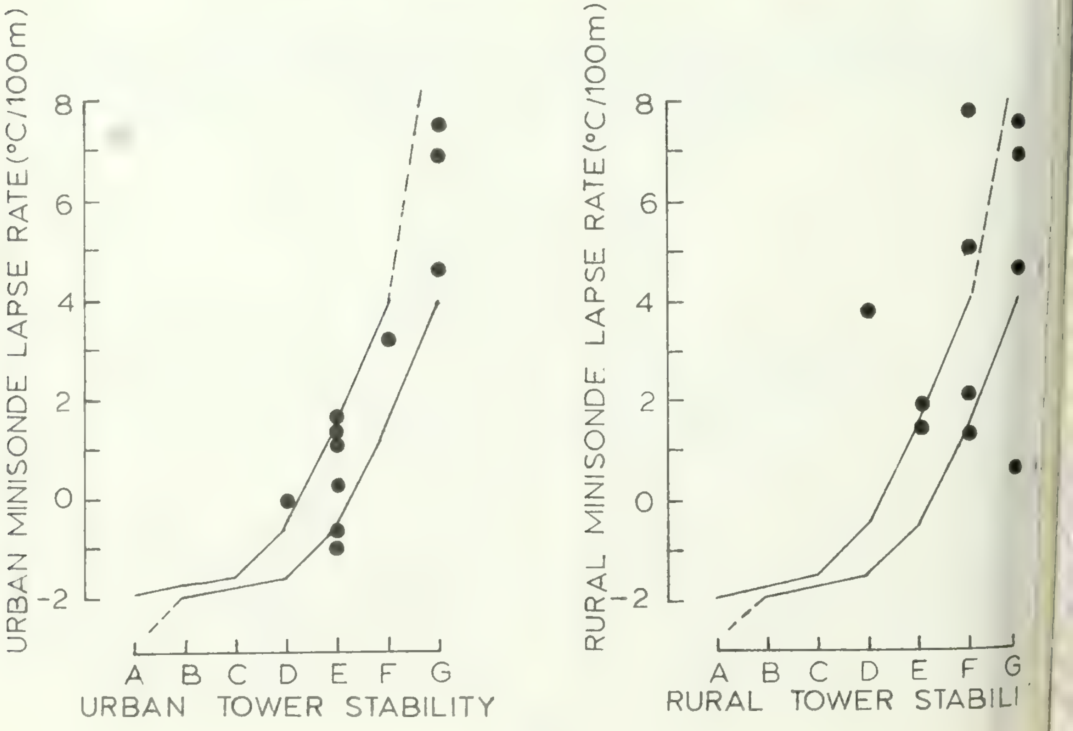
D, etc.) occurred on 83 percent of the occasions. If the cases of coinciding neutral stability (D) on both towers are excluded (such conditions being likely to occur under overcast conditions, regardless of urban or rural terrain), the following urban stability changes are obtained: no change 45 percent, decreased stability 53 percent, and increased stability 2 percent.

A comparative study of the nocturnal stability variations between 10.0 and 45.7 m with that between 10.0 and 91.5 m on the urban tower gave no difference in stability 69 percent of the time. For the other occasions, stability variations with height were almost equally shared between an increase and a decrease. Hence, it was inferred that vertical stability changes on the urban tower were relatively insignificant.

The tower data suggested that two dominant patterns are likely to occur in the lower urban atmosphere with stable nocturnal rural conditions: in one case, no change between urban and rural stabilities; in the other, a decrease of one stability category over the urban area. The latter situation is commonly assumed for estimating the vertical diffusion length over a city *(Gifford 1972)*. These nocturnal features are in general agreement with the detailed observations of temperature profiles previously discussed. In addition, the persistence of inversion conditions on the urban tower for a few hours after sunrise on several mornings (fig. 6) agrees with the minisonde results, which showed urban ground-based inversions around 0930 MST on 22, 23, and 28 November 1974.

A comparison of the 11 simultaneous upwind rural and urban minisond soundings at night with the rural an urban tower stabilities for the same tim periods is given in figure 7. From th urban profiles, lapse rates within th

Figure 7.—Comparison of the low-level lapse rates from minisonde ascents with the tower stabilities at night.



modified layers, or in some instances, the lowest 100 to 150 m above ground (cases of no modification) were estimated. The lowest 100 to 150 m were used to obtain the rural lapse rates also. In figure 7 the solid-dashed lines represent the envelope relationship between temperature gradients and stability *(USAEC 1972)*. In general, the urban tower stabilities showed good agreement with the minisonde derived urban lapse rates. There was slightly less agreement between the rural tower stabilities and the rural minisonde lapse rates. This was not surprising because the rural tower stabilities may not always be representative of conditions upwind of the city. This limited comparison suggested that the urban tower stabilities may yield reasonable approximations of diffusion characteristics within the modified urban layer over Edmonton and may be potentially useful in the development of an urban dispersion climatology of the area.

CONCLUSION

This preliminary investigation of the nocturnal temperature structure over Edmonton provided some experimental evidence of the manner in which a medium-size city can alter the lower tmospheric thermal regime and the asociated boundary layer structure. In ontrast to similar investigations for ther mid-latitude cities, the results here howed a wide range in urban-induced mperature modification (from inveron to adiabatic and in some instances, o change) when stable upwind rural ir is advected over the city.

On the average, nocturnal boundary layer depth seldom exceeded 100 m. Within this modified layer, lapse rates were often stable (inversion). Hence, it is suggested that the term "urban nocturnal mixing depth" would be more aptly replaced by the term "urban nocturnal modified layer" and that suitable techniques should be developed to predict this depth in which the lapse rate can vary over a wide range.

Case studies of the variation in the nocturnal boundary layer structure exhibited complex patterns that seem to reflect the heterogeneous nature of the urban surface. Urban tower gradients, expressed in terms of Pasquill Stability categories, indicated two dominant regimes: no change in stability, and a decrease by one stability category (less stable) as compared to simultaneous rural values. The determination of these urban stabilities from tower measurements could be applied usefully in developing an urban dispersion climatology for the area.

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Acknowledgments. Special thanks are due to the many participants in the Edmonton Air Pollution Field Study. They included groups from the Atmospheric Environment Service, Canada, the Department of the Environment of the Government of Alberta, the Department of Geography of the University of Alberta, and Western Research and Development Ltd. of Calgary. The experimental part of this study was conducted while the author was affiliated with the Atmospheric Environment Service.

Surface Air Temperature in a Maritime Metropolitan Region

by J. D. McTAGGART-COWAN *and* J. W. S. YOUNG, *respectively with the Atmospheric Environment Service, Environment Canada, Downsview, Ontario; and New Brunswick Department of the Environment, Fredericton, New Brunswick, Canada.*

ABSTRACT.—In investigations of the micrometeorology of any area, one of the basic parameters required is the spatial and temporal distribution of the surface air temperature. A mobile instrument mounted on an automobile was used for measuring temperatures within the surface mixed layer. Details are presented of a case study at Saint John, New Brunswick, in a summer period. The effects of topography, lakes, sea-breezes, and land-use characteristics are discussed.

STATISTICS for climatology of a region that are based on measurements taken at only one point fail to reflect differences in climate within the region. These differences can be especially significant in determining the scope of a tourist industry or in land-use planning on a regional and personal level.

One of the interests many people have is the distribution of surface air temperature within a region. During the summer months, some people like to stay near bodies of water where temperatures are moderated. Others prefer more radical climates where the air is drier but the temperatures vary greatly. Meteorologists are also interested in the surface isotherms, as they give an indication of the state of the atmosphere in the surface mixed layer.

A simple, mobile instrument for measuring these temperatures is described, and an example of the information that can be obtained is given for a maritime metropolitan region.

THE INSTRUMENT

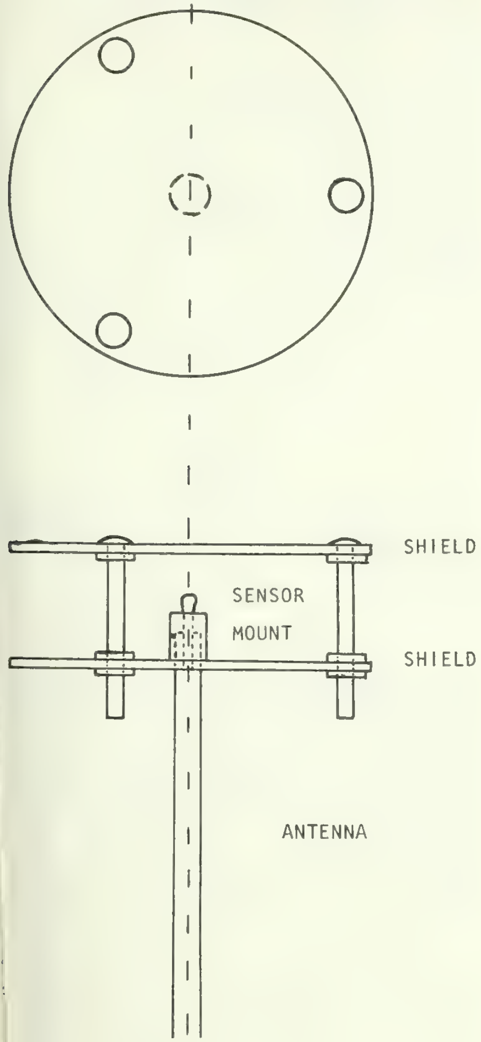
A rugged, dependable, and inexpensive direct-reading temperature system was developed for measuring the air temperature from a moving vehicle. It consists of a sensor and supporting structure (fig. 1), a simple circuit (fig. 2), and a digital voltmeter.

The sensor used is a dual thermistor made by Yellow Springs Instrument Company. These thermistors, when combined in a simple resistive network, produce a device capable of giving reproducible temperatures on a linear scale with a range of about 50°C. (The networks used in this system worked from −5°C to +45°C.)

The thermistor bead (YSI#44018) is mounted securely in a thermally insulating holder that is mounted betwee two circular plates about 7 cm in diameter. The separation between th plates is such that the bead is screene from the direct rays of the sun (excep at low sun angles) and cannot sense th road surface on either side of the transporting vehicle. These plates, held together by three thin vertical struts, ar painted shiny white on their outer surfaces and flat black on the inside surfaces. This combination serves as fairly effective radiation shield for th sensor by blocking off direct and r flected shortwave solar radiation whi permitting ample airflow past the senso

The bottom plate of the shield a the insulating holder attach to the to of a standard whip antenna, which mounted on the roof rack of an aut

Figure 1.—Sensor and supporting structure.

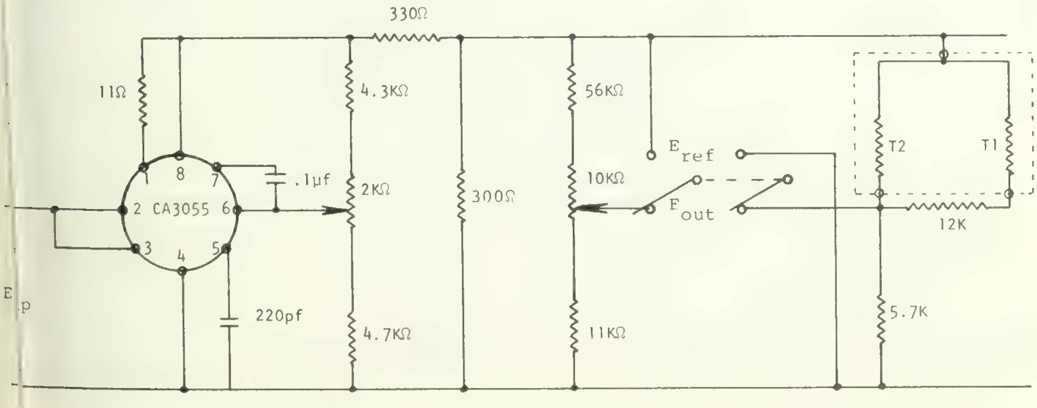


mobile. This allows the sensor to be placed several meters above the ground and at least 1 m above the roof of the transporting vehicle. Several advantages are gained by this type of mounting in that the sensor tends to be above the layer of air directly influenced by the road and thus samples in an area that represents the surroundings. The vehicle motion, which was maintained above 5 m sec^{-1} for all sampling points, produced adequate ventilation for the sensor.

Three wires lead down the mast from the sensor to the signal conditioner box inside the vehicle. This box consists of a constant voltage source generator (such as an RCA3055) working from a 9-V battery, a divider network to drop the output voltage of the regulated supply to a useful level, a zero-offset control, and the resistive network for linearizing the thermistor output. A swith is also included to permit monitoring of the regulated DC voltage, and a variable resistor control allows setting of that voltage when any drift due to system aging is detected.

The output of this box can be monitored by any DC voltmeter. A Weston Digital Voltmeter, Model 1240, was used during the field study reported in this

Figure 2.—The thermistor linearizing circuit. T1 and T2 are the sensor elements; E_{sup} is the battery supply voltage; E_{ref} is the reference voltage chosen using the thermistor's equation to yield a unit change in E_{out} for a 0.1°C change in temperature.



paper. This permitted the temperature to be read directly to 0.1°C. The absolute accuracy of the system is ±0.2°C without calibration, and the system is insensitive to air velocity above 5 m sec^{-1}.

THE FIELD PROGRAM

To investigate the spatial and temporal distribution of surface air temperature in the vicinity of Saint John, New Brunswick, Canada, two identical instruments were constructed, tested, and calibrated.

A grid was laid out on the city map, and a series of stations were identified, based on the criterion that a site selected was to be as close to the center of each grid square as possible but still on a navigable road. This produced 51 separate locations, which were divided into two courses, one on each side of the Saint John River. A continuous loop for each course was chosen, and this became the driving pattern for the two vehicles, each manned by a driver and an observer. Each course took about 1.5 hours of continuous driving to complete, and a minimum of five traverses was run each day.

The temperature at each station was obtained by averaging the readings taken during a 10-second interval centered at the preselected site. These values were then plotted against time to obtain 51 individual daily temperature curves. From these a series of surface isotherm maps was obtained for times corresponding to concurrent vertical profiling of the atmosphere. An example of these maps, showing isotherms drawn every 0.4°C, is given in figure 3. Complete data from this study are given in McTaggart-Cowan *et al. (1974)*.

RESULTS

From these isotherm plots, a number of clearly definable meteorologically influenced events can be observed. The isotherm plot made for 1430 local time on 16 July 1974 (fig. 3) shows the typical detail that can be observed during a sunny afternoon. Temperatur differences of 6°C are not uncommon in a distance of 8 km from the edge of the Bay of Fundy. These differences develop rapidly during the summer when the sky is clear.

This particular day also showed the

Figure 3.—Surface isotherms at 1430 on 16 July 1974. The city of Saint John, New Brunswick, straddles the Saint John River just at its mouth. (Map Scale: 1 cm=1780 m).

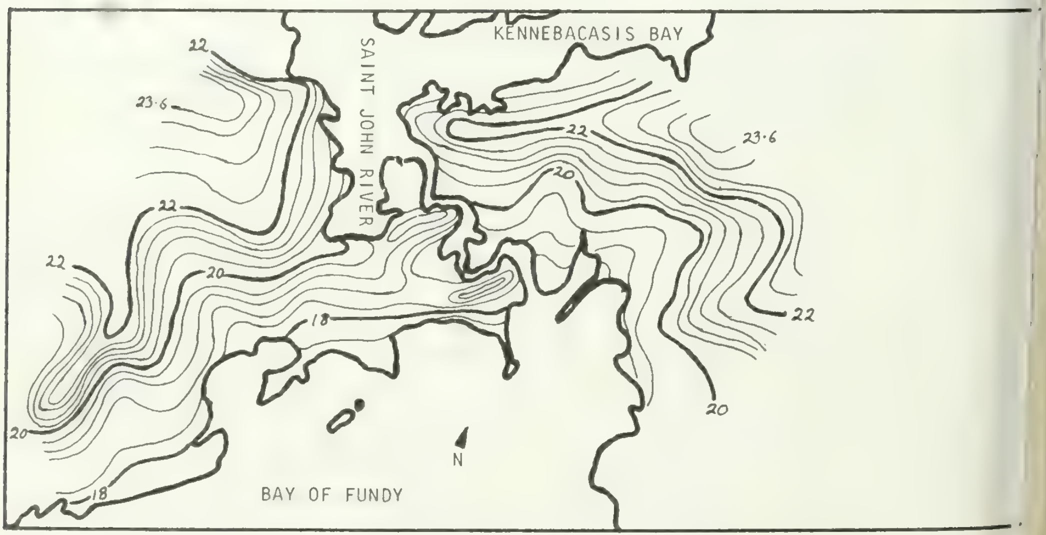
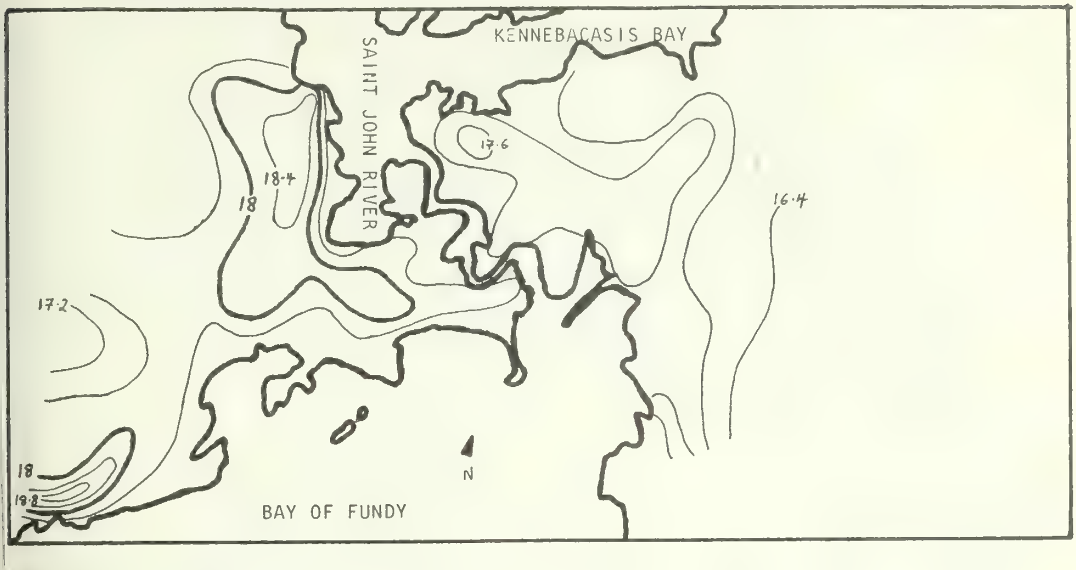


Figure 4.—Surface isotherms at 1000 on 16 July 1974, showing the effect of fog on the temperature gradient.



effect of fog. At 1000, the isotherm map (fig. 4) showed very little structure. The visibility in fog at this time was given as 6 mi, with the sky totally overcast. The sky cleared sometime after 1100, and convective-type clouds were reported by 1500, shortly after the 1430 profile. This type of cloud can be re- ated directly to the strong heating of he surface.

The effect of the sea breeze, a charac- eristic event of a maritime region, can lso be observed in figure 3. The bulge nland of the 20.0° and 22.0° isotherms n the right of the diagram is a result f the colder Bay of Fundy air intruding ver the rapidly warming land. In the orning before this developed, the flow as light northerly, but by the after- oon the southwesterly flow of the sea reeze dominated. This resulted in the urface mixed layer temperature near e water being warmer than that fur- er inland in the morning, but cooler ter in the day. The moderation of the urface air temperatures in summer ear a body of water is clearly shown.

Another example of the effect of a ody of water on the surface temperature can be seen in figure 5. In the western portion, the 14.0° isotherm can be seen directly downwind of a lake. The water temperature is higher than the air temperature and, with the westerly flow that was dominant at the time, a tongue of warmer air developed on the lee side of the lake. The splitting of this warmer air flow follows the topography.

Urban versus rural temperature differences can also be demonstrated by isotherm plots. The early morning distribution of temperature on 18 July 1974 (fig. 5) shows the heart of the city with a temperature of 13.2°C, while the countryside is typically below 12°C. This feature is usually masked during clear summer days by the locally generated air flow resulting from the city's proximity to the water.

The plot for 1100 on 18 July 1974 (fig. 6) shows an example of a late-morning situation on a clear sunny day. This plot is similar in complexity to the 1430 plot on 16 July (fig. 3), but has occurred more than 3 hours earlier. Only the full-degree isotherms are shown, as the principal purpose of the figure is to show the effect of topography on the

Figure 5.—Surface isotherms at 0700 on 18 July 1974, showing the effect of Ludgate Lake on the surrounding temperature field and the warming caused by the city center.

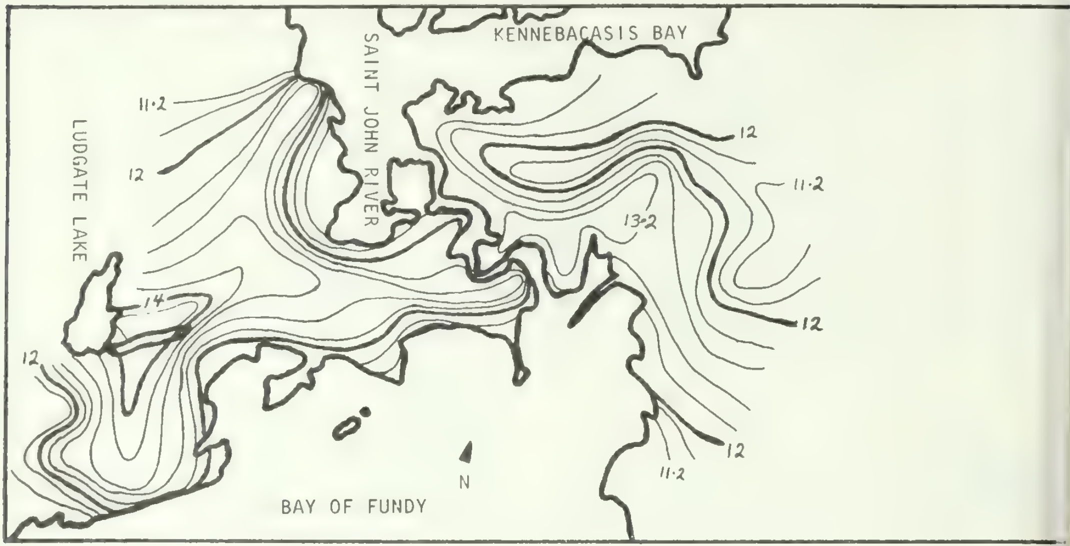
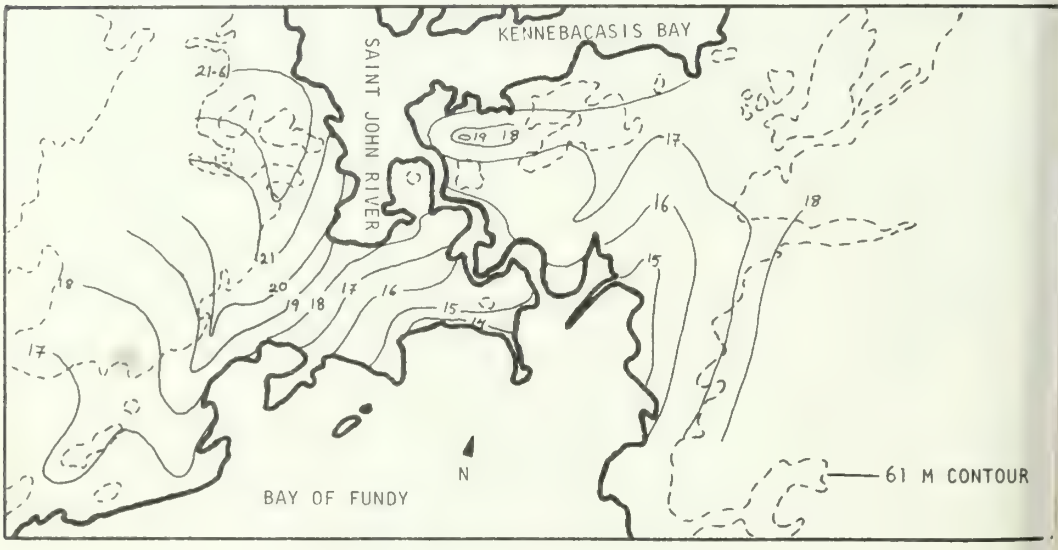


Figure 6.—Surface isotherms at 1100 on 18 July 1974, showing the effects of topography. The areas enclosed by the dashed lines (the 61-m contour) have an elevation above 61 m.



temperature distribution. The dashed lines show the 61-m contour. Two dominant hot spots can be observed, one in the upper center of the picture, and the other directly to the left of it. Each is in a valley protected from the sea breeze to the south. The inward thrust of th sea breeze can be seen to the right o the plot where it lines up reasonab well with the valley. On the west, th more complex topography tends to o scure the early effects of the sea breez

CONCLUSION

This technique for obtaining surface isotherms is both simple and inexpensive to operate. The results can be used to aid in land-use planning on several scales. Areas that have high summer daytime temperatures and are near water are naturals for good tourist-industry development, offering swimming and boating. Industrial development normally associated with coastal regions should be located in areas where gaseous effluent will not be carried inland to residential areas by the sea breeze on clear afternoons. Individual people can also use this type of information in a qualitative manner in choosing general areas of habitation.

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The Urban Heat Island in Akron, Ohio

by FRANK P. MARTIN *and* GRACE L. POWELL, *respectively weather service specialist, National Weather Service, Akron, Ohio; and associate professor of geography, University of Akron, Akron, Ohio.*

ABSTRACT.—Data gathered by automobile traverse were used to describe the urban heat of Akron, Ohio. Observations were made at 2100 or 2200 EST on four nights—17 April, 11 July, 10 October, and 2 January. Weather conditions not conducive to heat-island development were avoided. Temperatures in the center of the heat island were 6 to 14°F warmer than rural areas outside the city. The heat-island center was always over a mixed residential/commercial area. Topographic influences were apparent in the heat-island pattern.

MUCH HAS BEEN WRITTEN about the micro-climatic variations that have been found in some urbanized areas and hence have been assumed to exist in other urban centers as well. The most commonly documented urban impact on climate has become widely known as the "heat island."

Factors contributing to a heat island's existence are integral parts of urban areas — pavement, brick, concrete, asphalt, and other stone-like building materials; high volume of motorized traffic; large concentrations of heated and otherwise energy-serviced buildings; and industrial complexes. Despite the near certainty that a heat island can be identified in almost any urban center, the precise location and the magnitude of its development are anything but certain. The factors bearing on the way in which heat islands develop are reviewed as the heat island in Akron, Ohio, is examined here.

METHOD OF DATA COLLECTION

Data for this study were collected on the nights of 17 April, 11 July, and 10 October 1972 and 2 January 1973, using the automobile traverse method similar to that used by Hutcheon *et al. (1967)*. Weather on the days chosen for the investigation varied significantly enough throughout the days (and during the time of the traverse runs) to assure a fair representation of meteorological conditions. However, days with strong winds, cloud cover, and precipitation were avoided for data collection because these conditions weaken or eliminate heat islands. Week nights were chosen for investigation because Mitchell *(1953)* showed that increased human activity through the week days cause warmer urban temperatures than those that occur on weekends.

RESULTS

As may readily be seen (figs. 1 to 4), the center of the heat island in Akron formed over the same area on all four occasions — approximately 1.5 miles northwest of the central business district (CBD). The intensity of the heat island is indicated by the temperature differential between the edge of the city and the heat island center. The intensity varied with the season: 9°F in spring 6°F in summer, 14°F in autumn, and 7°F in winter.

The center of Akron's heat island i located over a mixed residential-commercial land-use area. The commercia activity is located in relatively low-profile buildings with large paved parking areas. These low-profile buildings have very little shadowing effect on eac other; hence considerable solar radiatio

Figure 1.—Akron's heat island location 2200 EST, 17 April 1972.

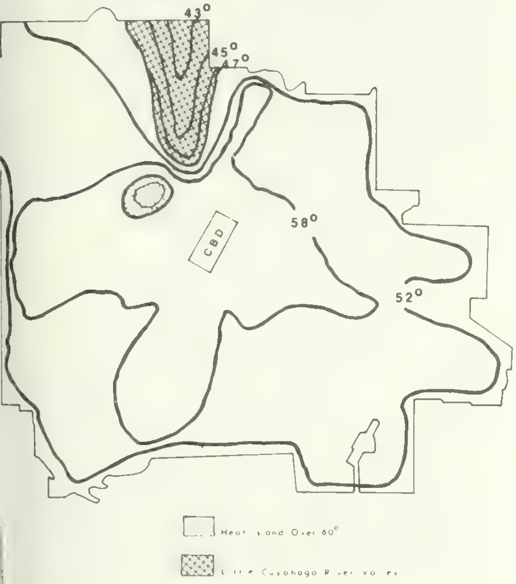


Figure 2.—Akron's heat island location 2100 EST, 11 July 1972.

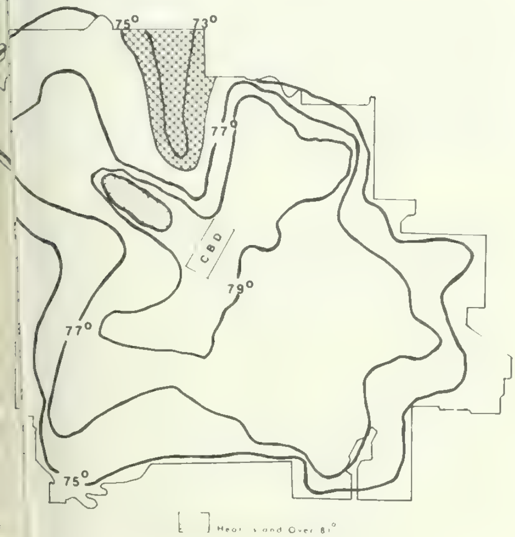


Figure 3.—Akron's heat island location 2100 EST, 10 October 1972.

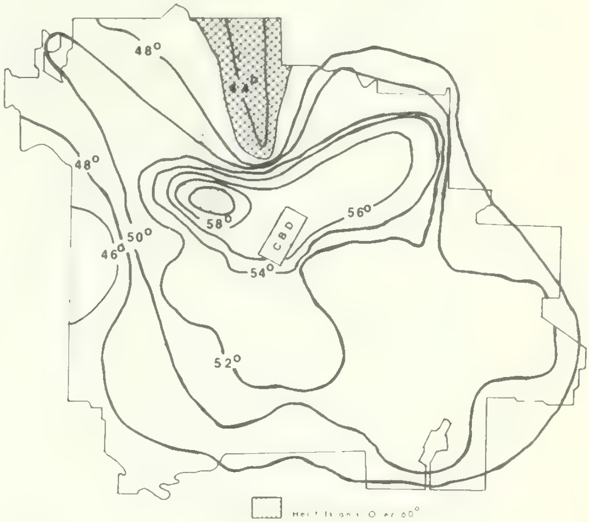
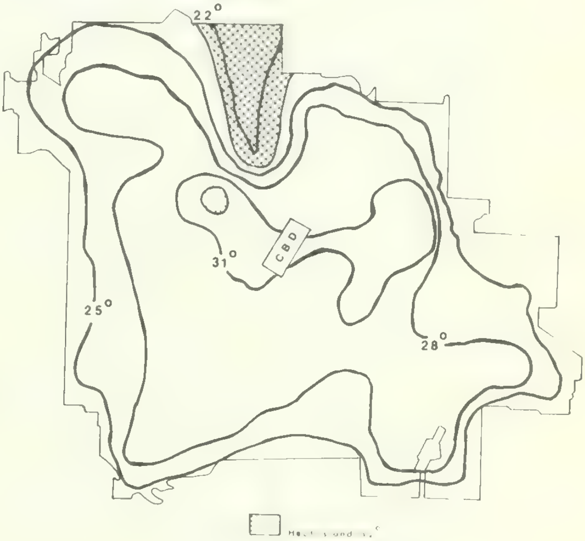


Figure 4.—Akron's heat island location 2200 EST, 2 January 1973.



is absorbed by them during the day. After sunset, the stone-like surfaces conduct heat to the urban air-causing excess heating.

The housing at the center of the heat-island area varies from modern multi-storied apartment houses to large frame (and a few brick) houses that are about 60 years old and have been converted into apartments. The average number of residents per apartment is three.

This concentration of apartments has resulted in the area having the second highest housing and population density in the city of Akron. The areas of the city that have the highest housing and population density are located on low-lying ground, and cold air drainage prevents the formation of a heat island over these high housing/population density areas.

The University of Akron Laboratory for Spatial and Cartographic Analysis has produced maps of Akron, using 1970 Census Data, which show the sections of the city with population density of 20 to 25 persons per acre and 6 to 10 houses per acre (figs. 5 and 6).

These population and housing variables are important, since human and animal metabolic heat, and waste heat from space heating (and cooling), all contribute heat to the urban atmosphere.

In addition, the heat-island center is located over relatively high ground that causes cold air to drain away from that area. The heat-island center is approximately 100 feet higher than the surrounding ground.

DISCUSSION

Since heat-island formation is due to the impact of man, it follows that heat islands can be reduced, intensified, or possibly eliminated by man's effort. Investigation into how to eliminate a heat island should become an area of research after its location and intensity is known Bach *(1972)* showed that wise land use can decrease the effect of heat islands

Some may question why this type o investigation should become importan and a source of intensive investigation The answer is simple — heat islands ar killers. Clarke *(1972)* and Buechle *et al. (1972)* have shown that the combination of increased heat and humidit of urban areas produces thermal stres

Figure 5.—Housing density in the heat island in Akron, Ohio (1970 Census data).

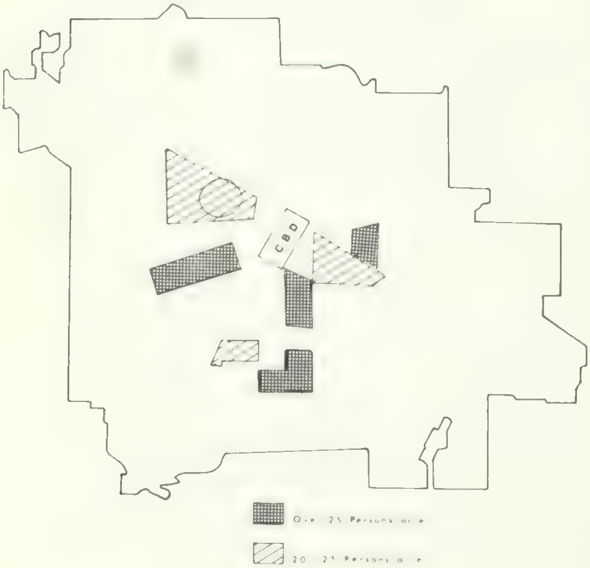
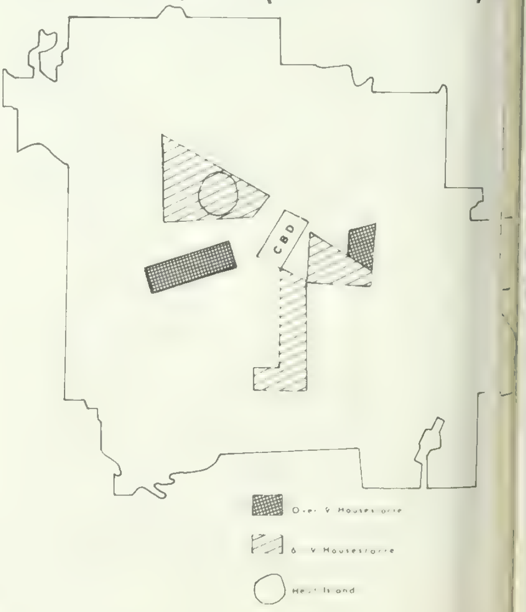


Figure 6.—Population density in the heat island in Akron, Ohio (1970 Census data).



ses, particularly at night among the poor and elderly, who are the predominate economic and age groups that live in the central cities.

These thermal stresses are a significant factor in causing urban mortality rates to be much higher than rural or suburban mortality rates during heat-wave conditions. The thermal stresses are produced because there is virtually no relief from heat and humidity in the urban areas at night due to the heat-island effect and the lack of air conditioning among the poor and elderly. However, in the rural and suburban areas, relief from thermal stress occurs once nocturnal cooling begins.

Just how significant this death rate can be was indicated by Bridger and Hefland *(1968)*. They studied the St. Louis, Missouri, area for July 1966 and found that, although the corporate limits of the city (at that time) contained only 32 percent of the metropolitan population, 85 percent of the heat-related deaths took place within the corporate limits. The urban death rate was 5.5 times as great as the rural death rate for the same time period. Other studies have indicated similar results.

CONCLUSION

Despite the prevalence of heat islands as urban climatological phenomena, their location, nature, and magnitude cannot be inferred on the basis of city size, industry mix, and housing density alone. Local climatological and physiographic conditions must also be considered. The net result is that, at least until much more work is done, each urban situation must be treated as a unique case. As this study has shown, careful and precise measurements need to be taken within an urban area to determine the nature, extent, and magnitude of heat islands.

The heat island in Akron is the result of the interaction of four variables: elevation, land use, housing density, and population density. A significant change in any of the four could cause the heat island to be weakened.

City planners should take such matters as those discussed in this study into consideration when making plans for urban expansion or building within the city, because whatever they do affects the microclimate. However, it seems that most planners have little knowledge of microclimatology. Unpleasant urban climates reflect both the lack of planning and the lack of knowledge of microclimatology.

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MICROSCALE METEOROLOGY IN METROPOLITAN REGIONS

Washington's "Free" 300-Station Microscale Weather Network

by THOMAS BLACKBURN, *meteorologist, Planning and Requirements, Office of Meteorology and Oceanography, National Weather Service, Silver Spring, Md.*

ABSTRACT.—This article is intended to encourage those planning to conduct meso- or microscale weather studies to supplement their sophisticated observing techniques and equipment with low-cost observations taken by volunteers. Such observations can often show high benefits per unit costs in expanding the geographical area of study, increasing the density of observations, or in verifying the validity of urban study findings. Techniques used in recruiting and sustaining the 300-station volunteer Washington, D.C., Network are described.

DATA FROM APPROXIMATELY 320 precipitation - observing sites within a 25-mile radius of downtown Washington, D.C., are recorded after each occurrence, under the sponsorship of the Washington National Weather Service Forecast Office (WSFO). About 150 of these sites record maximum and minimum temperatures once daily, and many report additional meteorological events of interest, such as high winds, hail, thunderstorms, ice storms, and floods. Observers mail in their reports at the end of each month, and a few report real-time weather events to the WSFO via recording telephone.

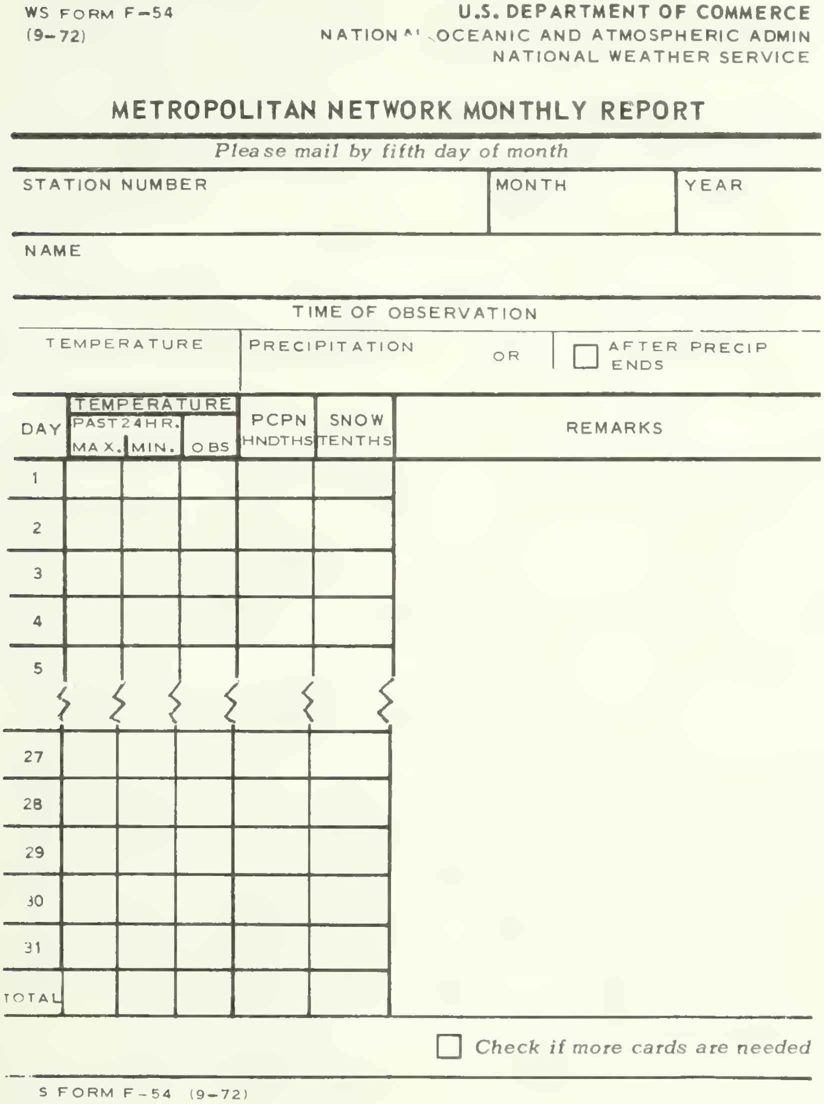
COSTS OF OPERATING WASHINGTON NETWORK

All observers supply their data to the Washington Network without pay, and the majority of them purchase and pay for their own equipment. The rest are participants in separate networks sponsored by the federal and county governments.

Bookkeeping, tabulation of the reports, and preparation of a monthly weather summary are done in off-duty time, largely by Stephen Flood and the author. Flood also puts in a limited amount of time during slack periods in his NWS work schedule. Many of the observers have also contributed their time generously.

There are two NWS cost items to the Washington Network. One is the printing of the Metropolitan Network Monthly Reports (fig. 1) costing less than 5¢ each. The reverse side of this form contains the mailing address. Mailing is free, using government franking privileges. The second cost item is the printing of the monthly weather summary, which averaged $43 per 8-page issue in 1974. Franking privileges are used to mail this free to volunteer observers and a few others.

Figure 1.—Metropolitan Network monthly report card, used by volunteer observers to record and mail observations.



WS FORM F-54
(9-72)

U.S. DEPARTMENT OF COMMERCE
NATIONAL OCEANIC AND ATMOSPHERIC ADMIN
NATIONAL WEATHER SERVICE

METROPOLITAN NETWORK MONTHLY REPORT

Please mail by fifth day of month

STATION NUMBER	MONTH	YEAR

NAME

TIME OF OBSERVATION

TEMPERATURE	PRECIPITATION	OR	☐ AFTER PRECIP ENDS

DAY	TEMPERATURE PAST 24 HR. MAX.	MIN.	OBS	PCPN HNDTHS	SNOW TENTHS	REMARKS
1						
2						
3						
4						
5						
27						
28						
29						
30						
31						
TOTAL						

☐ *Check if more cards are needed*

S FORM F-54 (9-72)

NETWORK INSTRUMENTATION AND DATA EXCHANGE WITH OTHER NETWORKS

Of the 320 rain-gage sites, 40 are re- rding and 20 are NWS standard 8- ch. Of the 40 recording gages, 34 are erated by county governments com- ring rainfall vs. runoff and flooding lationships between urbanized areas d the outer suburbs where urbaniza- on is planned. Most of the other re- rding gages are located at NWS and military weather stations at airports. The 8-inch gages are operated mostly by stations in the NWS climatological network. The network has an additional 20 or so clear plastic cylindrical rain-snow gages having an 11-inch capacity, and 240 wedge-type plastic gages with a 6-inch capacity. These are purchased by observers both for participation in the Washington Network and for their own use; they cost about $10 and $2.50, respectively, in 1975. These are significantly below retail, thanks to bulk purchases.

Maximum-minimum thermometers are of the U-shaped type, except for about 30 at NWS and military weather stations and in the NWS climatological network. The U-shaped thermometers were bulk-purchased for about $9 in 1974.

Temperature and rainfall data from climatological, county, and federal government stations are freely shared with the Washington Network; and summarized data from the Washington Network are shared with those operating the government networks.

POTENTIAL OF UNPAID VOLUNTEERS IN SUPPLEMENTING MICROSCALE STUDIES

The main purpose of describing the Washington Network is to suggest usage of the same type of data to augment other types of meso- or microscale studies. Suggestions for the establishment and maintenance of such networks are offered later.

It would be difficult to justify establishing much of a volunteer network to supplement short-period studies, such as 2 or 3 nights of temperature traverses, due to the time and effort required to establish it. However, the value of volunteer networks increases as the length of the period of the microscale study increases. Some suggested microscale studies using volunteer observers are discussed below.

Studies of the Influence of Urbanization or Terrain on Precipitation Patterns

Application of the low-cost Washington Network concept is most obvious as a supplement to urban precipitation studies. The appeal of volunteer observations lies in the use of a mix of simple and complex observing systems. For example, instead of setting up a network of recording rain gages about 2 miles apart, every other station in this 2-mile grid could consist of a simple rain gage operated by a volunteer. Use of the low-cost gages at about half of the planned observing sites would cut field instrumentation costs significantly. It is doubtful that estimations of rainfall rates and measurements of storm totals would suffer unduly from this substitution, even in the case of stationary thunderstorms with intense isohyetal gradients, especially if digital radar data were available for the study area to assist with analyses.

A correlary use of volunteer observers would be to intersperse these between recording gages installed at the pre-planned locations, as a means of increasing data density and hence, analysis accuracy. This type of use is particularly apropos for studying rainfall-runoff relationships (and for improving real-time flash-flood warning capabilities) over small drainage basins, o over somewhat larger basins lacking digital radar within a reasonable distance.

Urban-Heat-Island Studies

One of the main goals of urban temperature studies is to establish relationships between temperature and nonmeteorological factors such as terrain degree of urbanization, and vegetatio (TUV). Empirical relationships established between these in one metropolita area are most beneficial if they are exportable to other areas.

The establishment of reliable TU relationships to temperature over an sizable area can be quite difficult usin temperature traverses alone, due t short-period temperature changes o the number of simultaneous traverse needed. There are two means by whic volunteer observers may contribut First, they can be informed in advanc of the times of planned temperatur traverses, in order to coordinate thei readings. However, many traverses ar conducted during inconvenient hou (at night). This problem is partly ove come by the second method, which use volunteers having maximum-minimu thermometers. Readings by the volunteers need not be made at specific times if the traverses are made at or near times of maximum or minimum temperature.

An additional advantage of volunteers is their capability of taking readings over extended periods of time — a procedure that is usually impractical for temperature traverses. Extended records are beneficial not only for obtaining long-term averages, but also for getting several sets of samplings under different combinations of wind speed, cloud, and snow cover.

Pollution-Sampling Networks

Volunteer pollution observers judiciously scattered over a city could provide a low-cost yet valuable supplement to more sophisticated pollutant-measuring networks. Volunteer observers could either retain samples of their rainfall for certain types of air (or water) pollutant analysis, or expose other types of pollution collectors to the air.

Recruiting procedures depend on the type of sampling employed. Small, light samples could possibly be mailed after exposure, while the larger ones should be taken to a common collection point. For the latter, recruiting might be concentrated within a given office building, where volunteers could drop samples off t work.

Selection of pollution observers from re-existing temperature or rainfall networks offers about the best chance of btaining people of proven reliability, kely to be interested in participating, and capable of following instructions. andom recruiting can often result in olunteers lacking these qualities.

elationship of Urban Temperature atterns to Vegetation and Length of rowing Season

Costly temperature-measuring devices eed not be relied on entirely to determine the effect of vegetation on urban temperature patterns and vice versa. Much can be learned by comparing maximum and minimum temperatures taken by volunteers in builtup vs. forested areas. These same observers could also report the impact of weather and urbanization on plant life, such as flower-blooming dates and frost, fungus, and pest damage.

Washington's annual Cherry Blossom Parade would usually have to take place 3 weeks later if it were held in the northern part of the suburbs, yet still inside the Beltway. Volunteer observations have shown the growing season to be 3½ months longer in the warmest part of the heat island than in the outer suburb valleys 25 miles away in two of the past 4 years, despite variations in elevation of only 500 feet.

The increased evaporation rate in the heat island is probably the main reason the downtown Arlington Army-Navy Country Club requires more watering than the rural golf courses.

POTENTIAL SOURCES OF FREE OBSERVATIONS

There are two basic sources of free observations. One consists of existing observing sites and the other of potential new observers. Either source may be surprisingly easy to tap, and may provide more data than seem necessary in some areas. The acceptance of some redundancy can help compensate both for what might be less accurate observations and (in the case of extended-period studies) for dropouts and temporary observer absences during summer vacations.

Pre-Existing Observations

The following list includes potential sources of pre-existing observations. The number at the end of each source indicates the number of that type of observation in the Washington Network.

1. Airports (military or civilian) handling scheduled traffic. These take observations hourly. There are seven of these in the Washington Network,

each of which submits monthly summaries.

2. NWS climatological stations, or USDA experiment stations etc. recording maximum and minimum temperatures and daily precipitation (about 15).
3. Networks of recording rain gages operated by county governments or the U.S. Geological Survey (about 34).
4. Golf courses (5), farmers (15), utilities — electric and natural gas (5), who have an economic stake in weather.
5. Employees of the NWS, Geological Survey, or any other federal or local agency having an interest in weather (about 80).
6. Those having weather as a hobby, or interested in temperature and/or rainfall for lawn or garden growth and watering needs, or school earth-science departments and college meteorology or geography departments (about 50).

More than 200 of Washington's 320 observations were obtained from the above pre-existing sources. They provide the advantages of more weather knowledge and a lower turnover than in newly recruited observers, whose enthusiasm is more likely to wane soon.

New Observations

Sources of new observers would include those in (d) through (f) above who are not yet participating, the general public, perhaps 4-H or Future Farmers of America (if suburban data are needed), and retired people, who often are looking for a meaningful hobby useful to others.

Recruiting Suggestions

Several methods of finding existing observers and recruiting new ones have successfully been employed in Washington, and should be applicable elsewhere. Some are listed below.

1. Contact airports and NWS climatological stations. These must generall be contacted individually and supplied with envelopes in which to mai their reports. Names and addresse of climatological stations may be obtained from NWS substation network specialists, generally located a NWS forecast offices.
2. Put notices in local weekly or monthl news bulletins distributed to an organization's or business establishment's employees. One such notic put in a National Bureau of Standards weekly bulletin resulted in 3 new Washington Network observer
3. Set up model weather-observing stations at science fairs, county fairs, o state fairs. One of the most successful recruiting efforts was at an NW open house held outdoors and visite by many Washington-area scho classes.
4. Contact weekly or daily newspape likely to be interested in your projec Try to assure that the article promi ently emphasizes your desire to r cruit observers — a fact often buri toward the end of articles carried Washington papers.
5. Have a television station prepare short filmstrip describing your pro ect, and have it shown along with t regular TV weather forecast. Ma amateur meteorologists are av watchers of the TV weather pr grams.
6. Ask scientifically oriented organiz tions to permit you to request volu teers via their monthly meeting a nouncements. An announcement the local American Meteorologic Society monthly bulletin drew seve volunteers. Notices in local public tions of the American Association Retired People (AARP) should pro fruitful, at least for warm-seas observers.
7. Make house-to-house or farm-to-fa visits. Though this method may se difficult, these visits let you kn exactly where in your network ea

new station is located, its proximity to vegetation, valleys, and pollution or heat sources, and each station's instrument exposure.

A stock of weather equipment should be maintained for mailing or personal delivery to observers who do not have their own. Rain gages and maximum-minimum thermometers are purchased in bulk at reduced prices for distribution in the Washington area. The 11-inch capacity gages are purchased in lots of six for about $10 each, postage paid, from the Lake Region Rehab. Ind., Inc., P.O. Box 404, Fergus Falls, Minn. 56537, telephone 218-736-5668. The 6-inch capacity wedge gage comes from the Tru-Chek Rain Gage Div., Edwards Mfg. Co., Albert Lea, Minn. 56007, telephone 507-373-8206. These may be purchased for about $2.40 each plus shipping, in lots of 20. Maximum-minimum thermometers are purchased at a discount through one of our golf-course superintendent volunteers.

MAINTAINING THE INTEREST AND COOPERATION OF VOLUNTEERS

The retention of unpaid volunteers in extended period studies is highly dependent on frequent feedback showing the fruits of observers' efforts. This is achieved in two ways in the Washington Network. First, a letter of thanks is sent out annually with each new supply of weather-reporting forms; and second, observers receive copies of the monthly Metropolitan Climatological Summary (MCS). The summary contains: (1) analyzed maps of individual storms, on which each observer's rainfall amounts are plotted; (2) maps on which average and extreme maximum and minimum emperatures are plotted for each staion; (3) a table listing each observer's name, station number, and monthly and sometimes maximum 24-hour) preipitation; and (4) observer's comments nd descriptions of the month's weather vents both in the descriptions of inividual storms and a summary of the highlights of the month's weather events.

The success of the Washington Network in retaining the cooperation of its volunteers may be attested to by the fact that there has been no recruiting since 1972, during which time the Network has suffered a net loss of active volunteers of only about 50 (from about 370 to 320). Another 75 or so dropouts have been matched by word-of-mouth volunteers.

Figure 2 shows a sample MCS storm analysis. Note the use of observers' comments.

QUALITY CONTROL

Quality control covers both instrument accuracy and instrument exposure.

Instrument Accuracy

Rain-gage accuracy should be satisfactory if gages are of equal or better quality to those described above. Even the simple farm gages having no magnification are useful in the absence of other readings, provided precise rainfall amounts are not required. The U-shaped type of maximum-minimum thermometers should not be used unless it is possible to adjust upward or downward the maximum and minimum temperature scales independently of each other as may be needed to eliminate errors. This requirement excludes thermometers with scales printed on the frame. If money is of secondary importance, separate maximum-and-minimum thermometers meeting NWS specifications are preferred.

Washington Network thermometers are mostly of the U-shaped type with independently adjustable scales. Calibration is accomplished by placing all thermometers on a table in a room having no heat and cold sources and by circulating the air rapidly by a fan. Five separate sets of calibrations are run against a precision thermometer marked to the nearest 0.2°.

Figure 2.—Analysis of Washington area rainfall 25-26 June 1975. Solid lines are isohyetals of equal rainfall amounts, drawn at 1/2-inch intervals. Shaded areas received more than 2.50 inches of rain. Note use made of observers' comments in text at top.

RAINS OF JUNE 25-26

SYNOPTIC SITUATION AND EFFECTS

A weak "back door" cold front (a front coming in from the NE instead of NW) drifted southward through the DC area on the afternoon of the 25th, setting off heavy thunderstorms and locallized violent winds and some hail, all to the northern Va. and western Montgomery County areas of the NCA (National Capital Area). Then, after midnight, the heaviest rains of the year struck the Beltsville and northern Gaithersburg (Washington Grove) areas, setting off heavy flash flooding. Fortunately, these came at a time of day when little inconvenience resulted.

EVENING STORMS - HAIL AND WIND

Storms first formed about 4:30 p.m. in western Montgomery Co. and adjacent areas of northern Loudoun County. Goldstein (121) reported .24" rain by 5pm (and another .44" mostly between 6 and 7 pm). Seebode (318) heard thunder from this storm before a new storm formed overhead, bringing him up to 1/2" hail for 20 minutes and 1.44" of rain between 5:16 and 6:38 p.m. Swindler (321) also reported hail, as well as 45 mph winds.

Soon after this, new storms developed suddenly over Dulles Airport (403) eastward to the Vienna-Fairfax City areas, dumping over 2" of rain on both locales. High winds (from the storm's downdrafts) swept through a small area of western Fairfax City, where Adams (618A) reported strong gusty north winds, a corn crop flattened, extensive tree damage throughout the Cobbdale area, and heavy flooding, with 2.22" rain from 6:40 to 8 p.m. Weber (618) noted gigantic oak trees downed along route 123 and Hunter Mill Rd., and Atkiss (in Cobbdale) lost several trees and suspected tornadic activity. Mersereau (619) was soused with 2.25" of rain in an hour. MacNulty (927) observed the next big storm getting underway over and south of him around 8 p.m.

STORM CELL MOVEMENT

While the active thunderstorm cells were developing (not moving) southward through Fairfax Co., the upper layers of the stormclouds moved eastward, sprinkling much of the rest of the NCA with gentle rains. A multitude of observers commented on the long periods of the evening during which they heard distant and eventually overhead rolls of thunder, but experienced only light rains-after 1-2 hours of thunder.

POST-MIDNIGHT STORMS

To most of us it appeared that the thunderstorm activity had ended for the night, as thunder diminished by late evening. Not so. Shortly after midnight very locallized but drenching storms struck Beltsville, Layhill and Gaithersburg, with an abundant electrical display. Oliver (268) reported nearly continuous lightning and rain beginning 10 p.m., and ending by 5 a.m., with 3.45" rain. Nealis (267) reported "severe electrical storms from midnight to 2:30 a.m., streets flooded," and 5.88" of rain. Fisher (269) was also near the center of the "violent thunderstorm after midnight." In all, four stations received over 5" of water in the Beltsville area, while Whitcombe (35) recorded 5.60" in Washington Grove.

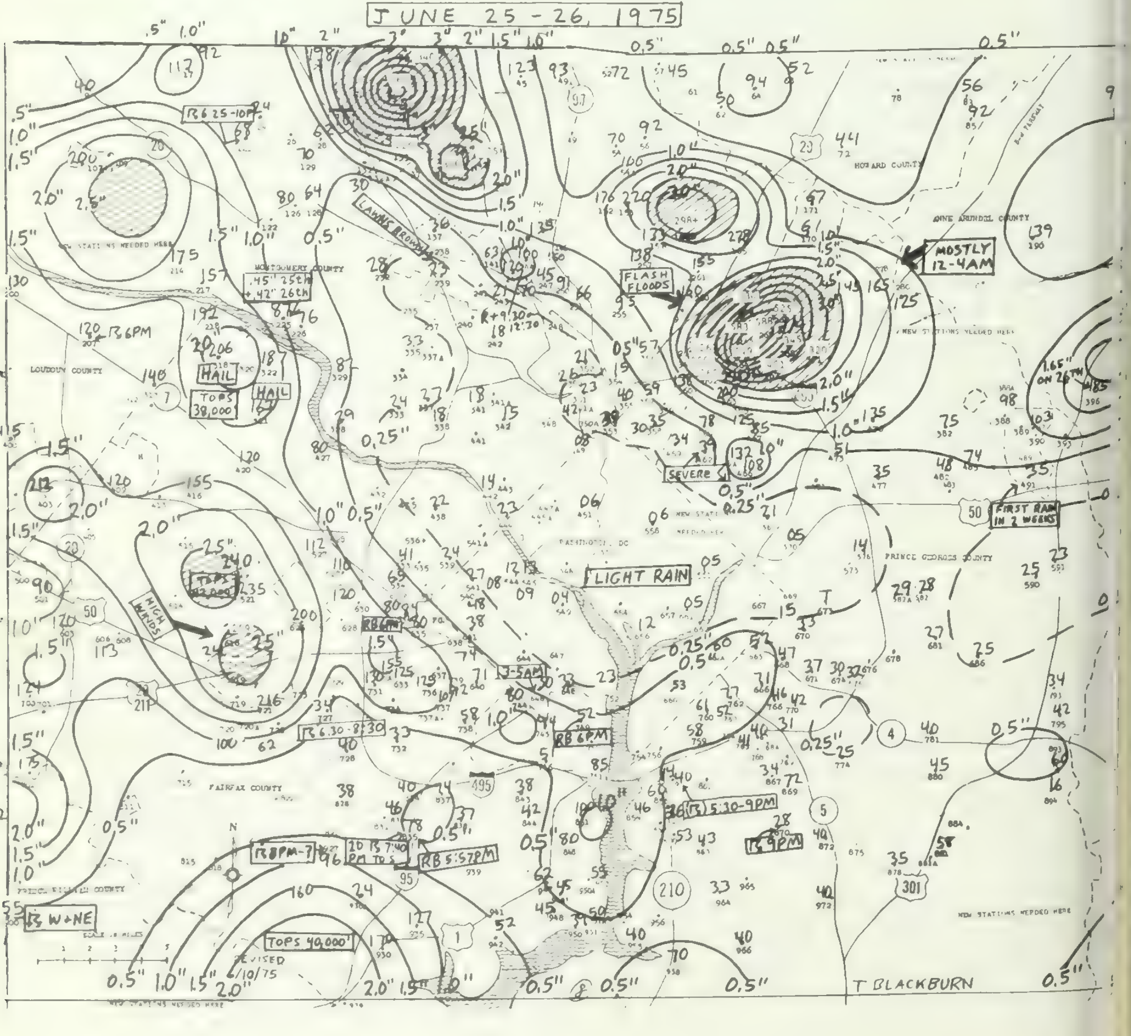
MIDNIGHT STORMS MORE LOCALLIZED AND PERSISTENT

While the evening storms in Va. moved around somewhat, thereby spreading out the area over which rains fell, the Beltsville storms had a net of zero motion, dumping all their rains in essentially the same spot. The cause of the change was apparently an increase in the low level easterly wind, that seemed to neutralize almost exactly the westerly winds at higher levels. Rainfall isohyetals were thus much more tightly packed than during the previous evening. The Beltsville storm was amazingly persistent, resulting in the following hourly amounts at Beltsville Plant Industry Station #7 (367):

12-1 a.m. 0.98"   2-3 a.m. 1.60"
1-2 a.m. 1.47"   3-3:40a.m. 1.27"

Note that the rate of fall per hour at 367 was less than in the Virginia storms, but the deluge persisted much longer.

Continued (see July 11-13 storm for conclusion of text)



Instrument Exposure

Instrument exposure can be checked at the time the instrument is installed, if done in person. Most new Washington Network instruments have been mailed out, and have had no such inspection. To compensate for this, detailed site-selection instructions are sent, together with occasional reminders in the MCS.

Inadequate rain-gage exposure may show up in readings inconsistent with adjacent data for rains having negligible isohyetal gradients. Such consistency checks, however, are only the poor man's substitute for on-site inspection.

Only about a fourth of the thermometers are located in official NWS "Cotton Region Shelters." The rest are usually mounted on the shady side of a structure, some with a small white shield installed on one side as protection from morning or evening sunshine.

Direct exposure to sunshine can usually be detected by plotting and comparing maximum temperatures on a clear windless day. Similar plots on uniform temperature cloudy days will often show up stations whose temperatures do not appear to fit the expected isohyetal pattern.

PROCESSING VOLUNTEER WEATHER OBSERVATIONS

The most obvious problem with the acquisition of a large volume of data regards how it is to be processed. Several day's work have been accomplished n an afternoon by assembling several of he volunteer observers to plot the past month's Washington Network rainfall amounts. One person reads the daily amounts from each monthly report, while each of the other participants plots the amount for his assigned rainfall date on a blank base map. Maximum nd minimum temperature plots can be andled by the same type of group ffort.

Initial analyses of the plotted data can e entered by the participant on a transparent overlay. The smoothed final product requires some training, however.

Observers have been very cooperative in totalling their own temperature and rainfall data.

REPORTING WEATHER AS IT OCCURS

Observers in the Washington Network have three options for telephoning weather data to the NWS Forecast Office as it occurs.

1. *Live Conversations.* The observer calls the forecaster, who takes the message live. This is used for urgent (severe weather) messages.
2. *Recorded Messages.* Significant, but not severe weather is recorded on a Code-a-Phone and played back by the forecaster once per hour, or more frequently during bad weather.
3. *Touch Tone.* Observers having touch-tone telephones send messages directly to a computer, which converts the tone signals first to a printout of the numbers sent (optional), and second into a formatted, printed plain-language message. This method can eliminate answering the telephone and manual computer input. However, it is not for the low-budget study, as a program must be written to decode the tones; a computer terminal is needed to display the observations; etc.

POSSIBLE USES FOR URBAN STUDY RESULTS AND OBSERVATIONS

There are a few uses of urban studies and observations that could be applied to improve the accuracy of daily forecasts, either by the NWS, or by private meteorologists, the latter being the more likely users in the immediate future. The NWS, however, has increased its interest in making detailed short-period forecasts to the point where the telephoned observations received are now used to issue hourly Washington metropolitan-area weather summaries and forecasts. Also, a special Summer 1975 project used data from volunteer observers on boats and at marinas to prepare similar detailed forecasts and warnings for Chesapeake Bay boaters. The latter observations are sent by touch-tone telephone.

Four possible uses of urban studies or observations are listed below.

Urban-Heat-Island Studies

Studies of urban temperature patterns could be used, for example, to show expected temperature *deviations* in different parts of the city from the official minimum temperature forecast. The change in the daily deviation would depend on factors such as wind, cloud, and snow cover. A sample procedure for doing this is shown below.

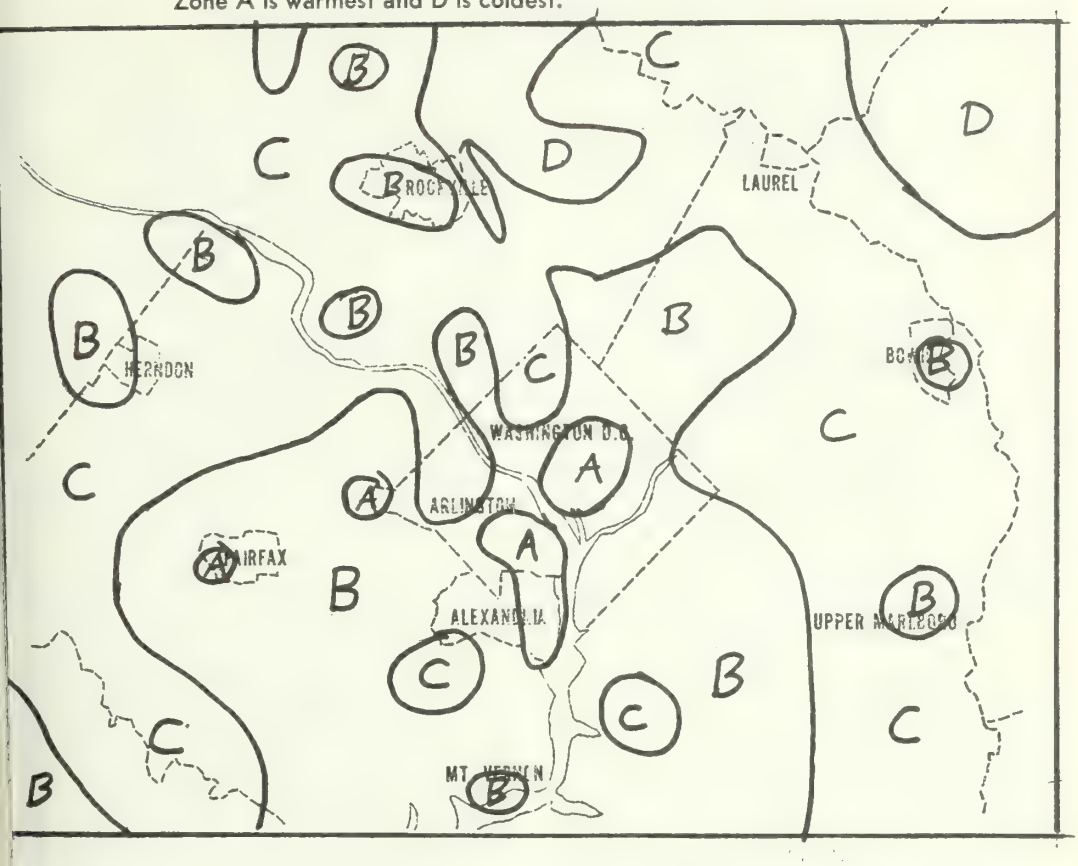
1. Take a metropolitan area for which isotherm patterns (at times of minimum temperatures) have ben determined, and divide it into about four temperature zones. Label the warmest and coldest zones Zones A and D, respectively, with Zones B and C having values between A and D.
2. Determine weather conditions associated with both the greatest and least geographical urban temperature variations, and about two other stages between these extremes. Call these conditions 1 through 4, condition 1 being weather associated with the least variation.
3. For this simplified example, assume that zones A and D will encompass the warmest and coldest areas, respectively, in each of conditions 1 through 4 and regardless of wind direction or any other variable.
4. Assign average temperature *departures* from the central heat island temperature for zones A through D for each of conditions 1 through 4. Zone A would be assigned a departure of 0°. Temperature *ranges* could be used instead of averages for each zone, in which case zone D might have a range from —14° to —18° instead of an average of —16° under condition 4.
5. Assume the official minimum temperature forecast for the city to be the minimum expected in the heat island. For example, a forecast of "low tonight 45° in the city of 30° in the colder suburbs" might mean minima of 45° in zone A and 30° in zone D, and average departures would be 0° and —15°, respectively.
6. Find a television weathercaster willing to read the official forecast, modified by the zone B, C, and D temperature adjustments. This assumes he or she is willing to forecast which of conditions 1 through 4 will apply.

Figure 3 shows a rough approximation (and gross simplification) of zones A through D for the Washington metropolitan area. The area shown is 45 miles wide — probably much larger than is needed, and the data base consists entirely of volunteer observers. Under conditions 1 and 4 the temperature differential between Washington's *adjacent* zones are about 1° and 5° F, respectively, although with snow cover, no wind and clear skies (which seldom occurs more than once per year), temperatures have varied by 26°.

Air-Pollution Distribution Forecasts

Should it be determined useful to predict which parts of a metropolitan area will suffer the severest pollution in the next day or so, studies of the relationship of low-level winds and other factors to pollution distribution could be used to make such predictions. The forecast procedure would be somewhat like that for temperature distribution, except that emphasis would be on the distribution and concentration of pollutants over the metropolitan area under different wind and lapse-rate directions.

Figure 3.—Smoothed temperature zones for Washington area. Zone A is warmest and D is coldest.



mprovement of Short-Period letropolitan Area Forecasts nd Warnings

While volunteer observations have een used extensively in tornado spotter etworks, their use in daily forecasts nd warnings has been rather limited. Real-time urban network observations an be a tremendous aid in the detection nd hence the issuance of short-period ail, heavy rain, flash-flood, local fog, ow, and wind warnings and forecasts. eports can also assist in the issuance detailed hourly synopses and fore-sts of metropolitan weather conditons. Knowledge of which sections of a y will receive rain during the next ur or two can be very useful to people gaged in activities such as boating d construction.

Real-time [illegible] perature reports received on days with precipitation accompanied by temperatures near freezing can be useful in the optimum deployment of snow-removal crews from above-freezing to below-freezing areas of a city. In the case of freezing rain, travelers advisories can be limited to below-freezing areas. Volunteer observations can also assist in monitoring the movement of the rain-snow line.

Improving Summertime Probability of Precipitation (POP) Forecasts

POP forecasts for metropolitan areas verify at a single observing point. Thus, if measurable rain fell at the verification point, a POP of 80 percent would have verified with only a 20 percent error (a 100 percent POP would have had no error) even if three-fourths of the rest of the metro area remained dry.

During seasons when rains tend to be spotty, I would like to see the POP verified against 5 or 10 evenly spaced observing sites, which could be operated by volunteers at essentially no cost. If 6 of the 10 stations reported precipitation, the best POP would have been 60 percent.

Verification procedures would have to be redefined to indicate the percentages of the metropolitan area expected to have measurable precipitation, rather than the POP at any given spot. Hopefully, this redefinition would increase the credibility as well as accuracy of summer forecasts. For example, while the radio listener now scorns a 30 percent POP forecast if he's in a downpour, he's more likely to believe it if it's defined to mean only 30 percent of the *area* will have rain.

An alternative to the rain-gage network would be radar determination of rainfall coverage. This is quite promising. The only problem noted in the Washington area is that the radar precipitation area often appears to extend 2 to 3 miles beyond the actual rain area. This problem should not be unsolvable.

Let's Make Quantitative Precipitation Forecast (QPF) Verification More Realistic

QPF's are verified for accuracy at a given point (the official metro area observing site). Though this method may be satisfactory for prolonged nonconvective rains, it can be gravely misleading during thunderstorm situations.

Rainfall amounts from the same 5 to 10 sites proposed for POP verification could be averaged to obtain a value more representative of the metropolitan area than single-station verification.

A second QPF verification scheme would use rainfall depths determined by radar. However, the accuracy of radar-determined convective rainfall amounts is such that rain-gage readings are needed to calibrate the radar. Nevertheless, radar-determined amounts alone should be preferable to single-station QPF verification.

Until the QPF verification method is changed, it will be difficult to evaluate QPF accuracy, as is needed before significant additional forecast improvement is possible.

Injury and Damage Claims

Lawyers and insurance companies are frequently in need of more localized meteorological data than that available from the official observing site. They are quick to question a wind- or hail-damage claim if the official site had none. A lawsuit resulting from a fall on a snow-covered sidewalk may be justified, but will be difficult to support if the officia station reported only rain and above freezing temperatures, and no other data are available. Lawyers and insurance adjusters frequently request data for a particular suburb of Washington D.C.

Structure of the Microclimate at a Woodland/Parking-Lot Interface

by DAVID R. MILLER, *assistant professor of Natural Resources, Natural Resources Conservation Department, The University of Connecticut, Storrs, Conn. 06268.* *This research was supported by funds provided by the Northeastern Forest Experiment Station through the Pinchot Institute for Environmental Forestry Research, Consortium for Environmental Forestry studies.*

ABSTRACT.—Radiation balances and vertical and horizontal profiles of air temperature, vapor pressure and wind speed were measured across the interface of a large asphalt parking lot and an 18-m-tall *Quercus velutina* forest. The partitioning of available energy over the adjacent areas shows steep gradients between the parking lot and forest microclimates. Horizontal temperature and humidity gradients across the interface were on the same order of magnitude as the vertical gradients above the respective surfaces.

URBAN ENCROACHMENT into forested areas is one of the major land- ise changes occurring in the eastern oastal region of the U.S. This transfer f forest land to urban uses takes place vith little knowledge of or thought iven to the maintenance of the forest s a naturally occurring environmental uffering system. It is possible, however, hat methods can be devised to success- ully mesh urban expansion into the orest environment while maintaining he ability of the forest to ameliorate he suburban climate.

This study was devised to quantify ne physical exchanges of air-trans- orted latent heat (water vapor) and nsible heat between and within for- ted areas and adjacent paved areas. nowledge of the magnitude and varia- ons of these exchanges can lead to the termination of the microclimatic im- ict of developments in wooded areas. also may allow the size, orientation, nd composition of proposed city plant- igs and greenbelts to be designed to aximize any ameliorating effect on the al city microclimates.

ENERGY BUDGETS

The radiant energy absorbed at the rth's surface (Rn) is dissipated by evaporating water (LE), heating the air (A), and heating materials on and below the surfaces (S).

$$Rn = LE + A + S \qquad [1]$$

There are other processes that may affect the surface energy balance, which are not included in equation 1, such as photosynthesis, respiration, and canopy storage of energy. These are very small consumers of energy and can be neglected in this case.

In a given localized urban environment with no vegetation, there is no large source of water for evaporation. Therefore, the available radiant energy is used primarily to heat the air and the various materials that make up the surfaces in the city.

$$Rn = A + S \qquad [2]$$

Buildings and paving, having large heat capacities, absorb large amounts of heat during the day, making S a much larger term than in a natural environment. Convection processes convert much of this to sensible heat immediately during the day and later into the night.

In adjacent vegetated areas the relative amounts of energy utilized in LE and A vary as a function of the type of vegetation, the soil moisture available for transpiration, and the potential evapotranspiration rate.

The ratio of the fluxes of sensible heat and latent heat (A/LE) or Bowen Ratio

$$\beta = A/LE \qquad [3]$$

can be estimated from the temperature and humidity gradients above the canopy:

$$\beta = \frac{Cp\,\rho\,Ka\,\frac{\partial T}{\partial z}}{\frac{Mw/Ma}{P}\,L\,Ke\,\frac{\partial e}{\partial z}} \qquad [4]$$

where: Cp = the specific heat of air
ρ = the air density
Ka = the turbulent exchange coefficient for sensible heat
T = the air temperature
Mw/Ma = the ratio of the molecular weights of water and air
P = the atmospheric pressure
L = the latent heat of vaporization
e = the vapor pressure of water in air
Ke = the turbulent exchange coefficient for water vapor
z = height

If the ratio Ka/Ke is known, or the equality of Ka and Ke is assumed, then equation 4 can be solved with measurements of the gradients of temperature and air vapor pressure. The Bowen Ratio thus determined can then be used with the energy balance, equation 1, to determine the fluxes of LE and A:

$$LE = \frac{Rn - S}{1 + \beta} \qquad [5]$$

$$A = \frac{Rn - S}{1 + \frac{1}{\beta}} \qquad [6]$$

The usefulness of the one-dimensional Bowen Ratio model is in question near a surface discontinuity. It is valid only when the vertical fluxes of LE and A are independent of height (z) above the canopy. Therefore, it can be used only when measurements are made within the internal boundary layer, which forms at the windward (leading) edge of a stand and thickens with distance downwind.

Little information on the boundary-layer thickness above very rough surfaces such as forests is available. Shinn *(1971)* calculated, from wind-tunnel shear-stress measurements above a simulated forest canopy (see *Sadeh 1974* for measurement details), that the thickness of this boundary layer (α) grew linearly with horizontal distance (x) for at least 25 canopy heights (H) from the leading edge.

$$\Delta\alpha = 0.08x, \qquad x \leqq 25H \qquad [7]$$

METHODS

Three towers were installed across the interface of a 1.8-ha asphalt parking lot and an adjacent black oak *(Quercus velutina)* forest in Storrs, Connecticut Lat. 41°47'30"N, Long. 72°14'30"W Wind speeds, air temperature, and humidity were measured with sensitive cu anemometers and aspirated thermocouple psychrometers at four heights o each tower, extending above the canop of the forest.

The forest was 20 m tall. One towe was located at the edge, one approximately 2H (H = tree height) within th forest, and one approximately 2H ou into the parking lot (fig. 1).

Net radiation (Rn), ground heat flu (S), and ground surface temperature were measured in both the parking lo and the forest with miniature net radiometers, heat flux disks, and thermocouples respectively. The instrumentation and data recording system used ar described in Miller et al. *(1975)*. Dat were collected during the summers o 1973 and 1974 under a number of different synoptic weather conditions.

Smoke tracers were utilized to observ the three-dimensional patterns of ai movements under various synoptic conditions. Smoke was released at sever

Figure 1.—Parking lot and edge towers and the experimental site forest vegetation of predominately black oak *(Quercus velutina)*.

heights at the edge and at varying distances from the edge.

RESULTS

The Energy Balances

Figures 2 and 3 show the partitioning of the energy balances over the two areas on a sample day, 4 July 1974. Flux of sensible heat (A) in the parking lot was calculated from equation 2. A and LE over the forest were calculated from equations 5 and 6 from gradients measured within the boundary layer as defined by equation 7.

The net radiant energy available (Rn) over the parking lot and forest vere within 2 percent of each other. The soil heat flux (S) was approxi- hately 20 percent of Rn in the parking ıt and 2 percent of Rn in the forest.

Most of the available energy above the orest (f) was used to evaporate water ($LE_f \approx .8$ Rn), while in the parking ıt ($_P$) most of the available energy was ed to heat the air ($A_P \approx .8$ Rn).

ir Temperatures and Humidities

The air temperature over the parking t warmed faster after sunrise and oled faster after sunset than in or over e forest. After sundown the parking- t air was cooler through much of the

Figure 2.—The parking lot energy budget, air temperature, surface temperature, and air vapor pressure, July 4, 1974.

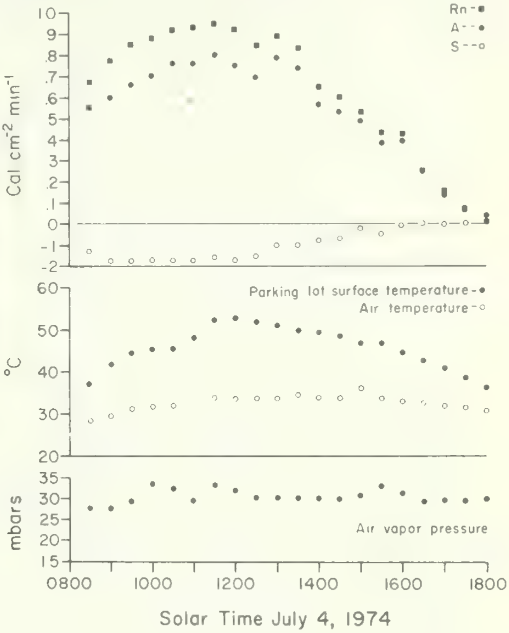
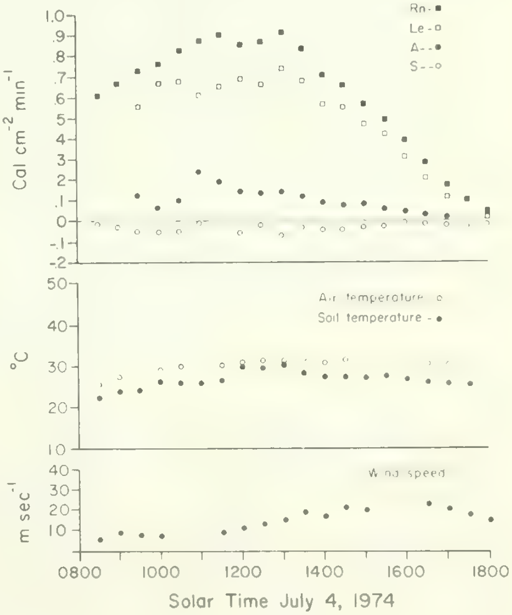


Figure 3.—The forest energy budget, air temperature, soil temperature, and windspeed (above the canopy), July 4, 1974.



night than the air under the forest canopy. This differential cooling and warming was in response to parking-lot surface temperatures, which ranged up to 55°C on some clear days. The daytime horizontal air temperature differences between the parking lot and forest were on the order of 3°C on warm days.

Air above the top of the canopy was heated most rapidly during the day and cooled at night similar to, although slower than air above the parking-lot surface. Therefore the profiles above the canopy were similar to but less steep than those above the parking lot.

The edge temperatures were similar in magnitude to those in the parking lot during the day, with slightly delayed heating and cooling responses. At night the edge temperatures were closer to those in the forest.

Vapor pressure data showed the forest to be consistently more humid than the parking lot. Near the ground the horizontal differences between the forest and open were generally on the order of 2 to 3 millibars both day and night.

Figure 4 demonstrates midday temperature and vapor pressure gradients across the edge on a clear day with the wind blowing into the stand *(Miller 1975)*.

Effects of Wind Direction

The data shown in figures 2, 3, and 4 are from periods when the wind was blowing into the stand.

Figure 4 shows steep horizontal gradients of VP just outside the forest edge and temperature gradients well into the forest. When the wind was from the forest, the horizontal temperature difference was smaller. The water vapor was apparently transported well out into the parking lot.

Figure 5 shows the forest energy balance on 6 July, a day with the wind from the forest. The ratio of A to LE above the forest on 4 July (wind into the stand) was slightly smaller than 6 July (wind from the stand). But no consistent trend in this effect could be correlated. Therefore the differences in ratio on these two days were ascribed to the higher potential evapotranspiration rates on 4 July.

Figure 4.—Air temperature isotherms (solid lines) and air vapor pressure isobars (dotted lines) across the parking lot forest edge with the wind blowing into the forest (after *Miller 1975*).

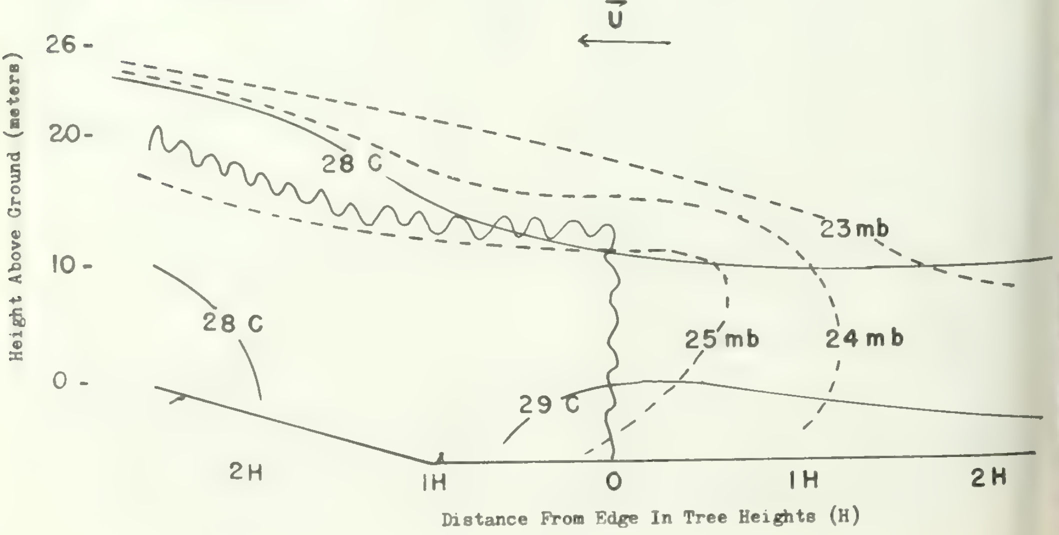
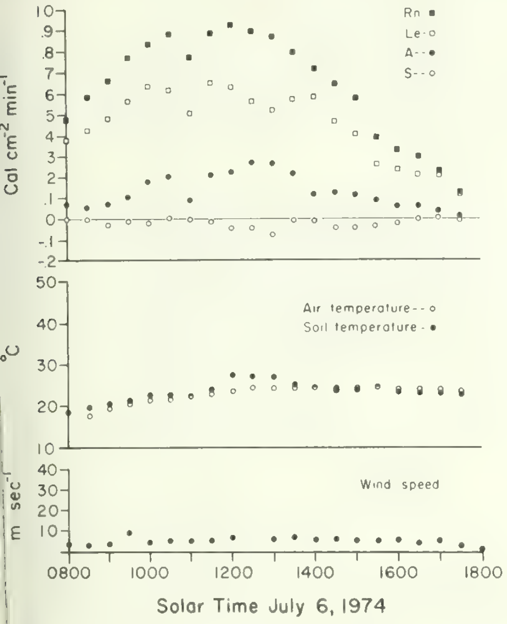

$\overline{U}$
26
20
10
0
Height Above Ground (meters)
28 C
23mb
28 C
25 mb
24 mb
29 C
2H
1H
0
1H
2H
Distance From Edge In Tree Heights (H)

Figure 5.—The forest energy budget, air temperature, soil temperature, and windspeed (above the canopy), July 6, 1974.



Advection Across the Interface

The term advection is used here to nean horizontal transport of an air roperty such as sensible or latent heat.

Smoke releases showed that the air rom the parking lot penetrated the forst edge easily and steadily when the ind direction was from the open to the orest. An occasional weak vortex apeared at the edge during periods of ery low wind speeds. Once the smoke enetrated the stand edge it drifted and issipated below the temperature inveron at the top of the canopy.

Calculations of the amount of sensible eat transported across the interface ere presented by Miller *(1975)*. From e horizontal temperature and wind eed gradients it was estimated that tween 10 and 20 percent of the senble heat produced on the parking lot as advected into the adjacent tree and.

DISCUSSION

The profile data suggest that the region of the interface can be broken into three distinct microclimates. One is formed over the forest, and its characteristics are determined primarily by the energy exchanges at the top of the canopy. The second is formed beneath the canopy. The third is formed over the parking lot and is characteristic of the exchanges at that surface.

The characteristics of the interfaces or mixing boundary layers between the three air masses change both spatially and over time as each of the microclimates responds to changing conditions. Apparently the interface between the parking lot air and that beneath the canopy moved horizontally and was within the forest edge during the day and outside it at night. This indicates that when sensible heat moved horizontally, from the forest at night and to the forest during the day, the major portion of the air mixing takes place some distance beyond the edge in the direction of movement.

These findings combined with those of Bergen *(1975)* indicate that the edge effects extend about 2 to 3 tree heights into the forest. Here the horizontal temperature gradients and wind velocities decreased rapidly inside the forest. At the tower site approximately 2H into the forest, the temperature gradients and wind speeds were very weak, indicating little if any advection that far into the forest. The effects of the edge on the air turbulance were indicated by Bergen *(1975)*, who calculated increased drag on the air mass some 30 meters (approximately 3H) downwind of a clearing in the forest.

The extent of the edge effects into the parking lot are a little less clear. The smoke tracers showed that with wind from the lot, air from greater than 2H penetrated the edge when the windspeed was greater than 4 mph. When less than 4 mph only the smoke released near the edge penetrated. When the wind was from the forest there were changes in the temperature and vapor pressure gradients well beyond the location of the tower located 2H into the parking lot *(Miller 1975)*.

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Outdoor Comfort of Pedestrians in Cities

by EDWARD ARENS *and* DONALD BALLANTI, *respectively climatologist and meteorologist, Environmental Impact Planning Corporation, San Francisco, Calif. Edward Arens is now with the Architecture Research Section, Center for Building Technology, National Bureau of Standards, Washington, D.C.*

ABSTRACT.—The outdoor comfort of pedestrians has been neglected by architects and planners because of difficulties in determining comfortable and uncomfortable climatic conditions and predicting the climatic characteristics of a planned urban site. Available information on comfort in a cold environment is summarized. The mechanical effects of wind on comfort are better understood than the thermal effects of climate and have proved to be practical criteria for assessing pedestrian comfort in designs. Climatic-prediction techniques and a procedure for determining the probability of discomfort on a proposed site are described.

HUMAN COMFORT is determined by many factors, both psychological nd physiological. Some of these factors, ıch as acoustics and indoor climate, ave an extensive history of quantificaon and control. The existence of standds for these variables requires that ey be considered in design.

Other factors, such as outdoor visual ects (light, surface, forms) and spatl relations (enclosure, security), tough not quantified or standardized, e of concern to the architect and are ituitively incorporated in design.

The effect of outdoor climate on comft, however, is often ignored by the ahitect or planner. It has been negcted to date because of difficulties in () determining what climatic conditins are comfortable or uncomfortable, ad (2) predicting the climatic characteistics of a planned site.

n this paper, available information abut discomfort due to wind effects is sumarized and tentative design criteri are presented. A model describing peestrian cooling in a cold climate is al given, and its shortcomings in defing design criteria are described. Desi criteria from these two methods ar applied to an urban site, using climatic data and data from wind- tunnel and sun-shadow tests on a scale model. A procedure for designing for outdoor comfort by controlling wind and sun (the most important and most easily varied factors) is presented.

INFLUENCES OF CLIMATE ON COMFORT

Mechanical Influences of Wind

Wind influences comfort through pressure effects and particle transport. Wind pressure affects comfort through disturbance of clothing and hair, resistance to walking, and buffeting of the body and carried objects like umbrellas. Comfort is also affected when the wind lifts dust and grit particles to eye level, or drives rain horizontally into the eyes or beneath clothing. At higher speeds, wind can also interfere with walking and cause safety problems.

These different effects begin at different wind speeds. Their threshold velocities suggest the onset of various types of discomfort and perhaps the basis for some wind-comfort criteria.

A summary of wind effects in terms of the well-known Beaufort scale (table 1) is taken from a land-effects version prepared by the British Meteorological Office, with additions by Penwarden *(1973)*. Most of the included effects have been observed by ourselves and others in the natural wind and in wind-tunnel experiments *(Arens 1972)*.

Although the Beaufort scale is commonly used to describe velocities averaged over perhaps an hour, our observations show that the wind effects listed for each Beaufort category correspond more closely to the wind velocities observed as they happened. The averaging time might be on the order of, say, a minute and includes the effects of small-scale gusts and lulls but not large ones. Therefore an hourly averaged wind in one Beaufort category will probably include gusts that cause effects ascribed to higher Beaufort categories.

Wind pressures in steady winds

The wind pressure on the human body and the angle of lean needed to counteract it are summarized in the equation *(after Penwarden 1973)*:

$$\frac{1}{2} \rho u^2 A_P C_D / W = \tan \theta / \cos \theta$$

in which θ is the angle of lean from the vertical to counteract wind.

$$\tan \theta = \frac{\text{wind force}}{\text{body weight}}.$$

W is body weight.

$\frac{1}{2} \rho u^2 A_P C_D$ equals wind force.

ρ is the density of air.

u is wind speed.

A_P is projected surface area normal to wind, found to be 0.3 total body surface area for frontal winds *(Pugh 1971)*.

C_D is a dimensionless drag coefficient, experimentally determined to be between 1.0 and 1.3 *(Pugh 1971)*.

$\cos \theta$ is a term reflecting reduction of A_P with lean.

Total body surface area (A_{Du}) is ob- tained from body height and weight b DuBois formula:

$$A_{Du} = 0.203\ W^{0.425} \cdot h^{0.725}$$

in which W is in kilogram force (kgf) and h is in meters.

Assuming a man of 75 kgf, 1.8 meter height, total DuBois surface area o 1.93 m², and drag area of 0.84 m², th relation between wind speed, drag force and angle of lean can be calculate (fig. 1).

Energy required to walk against a steady wind

The rate of performing external wor is the product of the wind force ar walking speed:

$$\text{Work rate} = \frac{1}{2} \rho\ (u+V)^2\ A_P\ C_D\ V$$

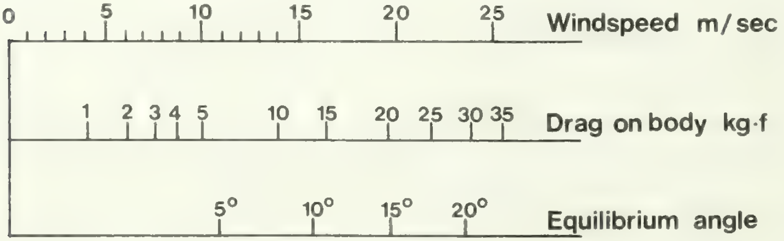
in which V is the velocity of walkir into the wind.

The total increase in metabolic rate the body M resulting from the work walking into the wind is

$$\Delta M = \frac{1}{2} \rho\ (u+V)^2\ A_P\ C_D V / \eta$$

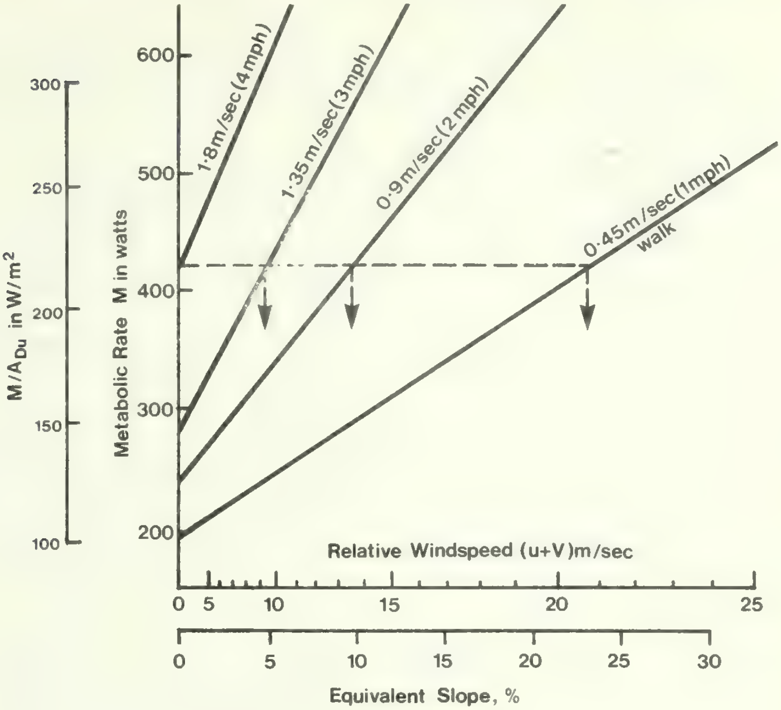
in which η = mechanical efficiency, (work rate) / (metabolic rate), whi Pugh *(1971)* found to be 0.44 for wa

Figure 1.—Wind forces and equilibrium angles.



Adapted from A D Penwarden 1973

Figure 2.—Work rates of walking against the wind *(Penwarden 1973)*.



ng against the wind and 0.33 for climbng hills. Penwarden *(1973)* presented hese data in a diagram (fig. 2) in hich the metabolic rates required for alking into the wind are compared to hose for walking uphill. The metabolic ates are expressed in watts and in atts/m^2 for the man mentioned above. enwarden *(1973)* suggests that, if the pper metabolic rate limit for average nathletic people is taken as 220 watts/ ^{2} (equivalent to walking 4 mph in still r), walking speed into the wind is duced as follows:

ind speed	*Walking speed*	
m/sec)	*(m/sec)*	*(mph)*
0	1.8	4
9	1.35	3
14	.9	2
21	.45	1

These values may be compared to the subjective estimates in the Beaufort scale (table 1).

Effects of turbulent winds

Wind at the pedestrian level is accompanied by turbulence, which is perceived as a varying velocity, as gusts, or as eddies. The intensity of turbulence for any given windspeed varies from place to place but tends to be greater in urban or built-up surroundings than in open countryside.

To learn the effect of most natural winds on comfort, it is necessary to quantify the influence of the turbulent component of that wind. This information has not been available until very recently.

In an exemplary study, Hunt and others tested subjects in both steady and turbulent winds in a wind tunnel *(Hunt et al. 1976, Poulton et al. 1975)*. They also tested the effects of wind variation over a short distance, such as when one walks out of a doorway into the wind. They assessed wind influence on comfort, disarrangement of clothing and

Table 1.—Summary of wind effects

Beaufort number	Description	Wind[1] (m/sec)	Effects
0	Calm	0	Calm
1	Light air	0-1	No noticeable wind; direction shown by smoke.
2	Light breeze	2-3	Wind felt on face; newspaper reading becomes difficult.[2]
3	Gentle breeze	4-5	Wind extends light flag; hair is disturbed; clothing flaps.
4	Moderate breeze	6-7	Dust, dry soil, and paper raised; rain and sleet driven;[2] hair disarranged.
5	Fresh breeze	8-10	Force of wind felt on body; drifting snow becomes airborne; limit of agreeable wind on land.
6	Strong breeze	11-13	Umbrellas hard to use; difficulty walking and standing; wind noise in ears unpleasant; windborne snow above head height (blizzard).
7	Near gale	14-16	Strong inconvenience felt when walking.
8	Gale	17-20	Generally impedes progress; great difficulty with balance in gusts.
9	Strong gale	21-24	People blown over by gusts; slight structural damage occurs; slate blown from roofs.
10	Storm	25-28	Seldom experienced on land: trees broken or uprooted; considerable structural damage occurs.

[1] Rounded from knots in the original scale. (1 m/sec = 1 meter per second = 1.94 knots = 2.2 miles per hour).

[2] Our observation.

Table 2.—Summary of wind-pressure effects on people

[Symbol < denotes 'should be less than']

Wind and effect	Criterion
Steady uniform wind:	
For comfort and little effect on performance	$u <$ 6 m/sec
For ease of walking	$u <$ 13-15 m/sec
For safety of walking	$u <$ 20-30 m/sec
Non-uniform winds (if u varies by 70% over a distance less than 2 m):	
To avoid momentary loss of balance and to be able to walk straight	$u <$ 9 m/sec
For safety (for elderly people this criterion may be too high)	$u <$ 13-20 m/sec
Gusty winds:	
For comfort and little effect on performance	$u_s <$ 6 m/sec*
Most performance unaffected	$u_s <$ 9 m/sec
Control of walking	$u_s <$ 15 m/sec
Safety of walking	$u_s <$ 20 m/sec

*Note: u_s is not the "peak gust" as used in engineering.

Source: Hunt and others (1976).

hair, eye watering, performance of tasks, and balance while standing and walking. Quantification was based on subjective verbal assesments by the subjects and on physical measurement of task performance and of wind forces while walking as transferred to an instrumented floor.

These findings show people to be very sensitive to turbulence in the wind. To compare turbulence effects to other win effects, an equivalent steady wind i defined:

$$u_s = u\ (1 + 3 \bullet \text{turbulence intensity})$$

in which

u_s = Equivalent steady-wind velocity.

u = Mean velocity.

turbulence intensity = (root mean squa of the instantaneous

deviations from
the mean
velocity)/u

The limiting velocities have been summarized (table 2).

Wind-driven rain and particles

A pedestrian may also be inconvenienced by rain or grit blown into his face. Blowing grit may well be the most unpleasant single effect of the climate on a pedestrian.

The suspension of a solid or liquid particle requires an upward air velocity equal to the terminal velocity of the particle (table 3). A horizontal wind equal to or exceeding the terminal velocity will cause a particle to descend at an angle of 45° or less to the horizontal.

It can be seen that a horizontal wind peed of 7 m/sec will cause large rainrops to descend at 45°. This value is sed by building climatologists for riven-rain data; however, fine drizzle will be driven at 45° by velocities as low s 1 m/sec.

The size of droplet and angle of fall hat individually and in combination are considered unpleasant are unknown. It probable that flatter angles of descent are acceptable for smaller droplet sizes, since wetting by rain takes time. This might allow us to define a single limiting velocity for rain. We do not have information at present, but it will be between 1 and 7 m/sec.

Wind-lifted dust has a major impact on human comfort. In the Beaufort scale, dust and loose papers are described as being lifted at velocities between 5.5 and 8 m/sec.

A physical formulation of this process depends on a number of unresolved factors such as the minimum particle size needed to cause irritation in the eye and on the skin, the mechanisms of particle lifting from urban paved surfaces, and the extent to which moisture cements particles together.

The lifting mechanism is described by Bagnold *(1941)* and Chepil *(1965)* in relation to desert sand and soil particles, respectively. Bagnold shows that particles begin rolling at around one-seventh the velocity needed to lift them. This suggests that grit traps (lawns, gratings, and water) might be useful in reducing the supply at the surface.

Lifting requires vertical velocities that are inherent in a boundary layer over a surface or that are caused by obstructions protruding from the surface. When the eddies are caused by surface friction, Bagnold shows that a horizontal velocity at 1.5 meters of 8 to 14 m/sec will lift 0.1-mm grit from flat surfaces.

Near wind-deflecting vertical obstructions, the vertical velocities close to the ground for a given mean wind speed are much higher. These vertical velocities may be in the form of vortices in fixed locations relative to the obstruction. Examples are eddies behind lamp posts, near building corners, or in streets near moving vehicles. Although these local eddies may lift dust and paper when the winds are light, they are often not perceived because the dust supply in their immediate area is exhausted.

Wind between 5 and 8 m/sec will probably cause pedestrian discomfort by blowing dust, paper, or rain.

e —Terminal velocities of airborne particles

Diameter particles	Character of particles
mm	
0.01	Dust
.03	Extremely fine sand, dry snow
.1	Fine sand
.2	Medium sand, snow, sleet, fine rain
.3	Average sand in the desert
1.0	Large raindrops*
1.0+	Sand to pebbles, great rain, hail

es: Bagnold *(1941)*, Reidat *(1970)*.*

Design criteria: mechanical wind effects

The British Building Research Establishment recommended 5 m/sec as the design wind velocity under urban outdoor conditions *(Wise 1970)*. As described above, recent results by Hunt et al. define this design value more closely in terms of the steady and turbulent components.

With a design value in hand, the designer must judge what percentage of the time (or how often in a year or season) it may be exceeded. For comfort, 10 to 20 percent may seem reasonable. For safety, lower exceedance percentages (say 1 percent) should be applied to the higher design values. Davenport *(1972)* has suggested acceptable exceedance frequencies for a variety of activities based on a 5 m/sec design windspeed; the reasons for the suggested frequencies are not given.

Penwarden *(1974)* analyzed cases of shopping centers that had caused wind complaints. He found that in centers where 5 m/sec was exceeded 20 percent of the time or more, the owners invariably spent the money to add protective screens or roofs. Centers with frequencies of 10 to 20 percent caused complaints but no remedial action, and few complaints were heard in centers with frequencies below 10 percent. Penwarden's study gives the most concrete evidence in support of specific design criteria to date.

THERMAL INFLUENCES OF CLIMATE ON COMFORT

A person's thermal comfort is influenced by the surrounding air temperature, wind, radiation, and humidity, as well as his clothing insulation and activity level. Thermal comfort has been studied extensively for indoor conditions (see *Fanger 1970*).

Because of the increased range of climatic variables outdoors, investigators have not been able to quantify the perception of thermal comfort versus climate in outdoor environments. See Penwarden *(1973)* for a summary of such work.

Most attempts to define the effects of climate on people have used thermal budget models in which it is assumed that comfort results from the thermal balance between the body's heat production and heat losses to the environment. These models assume equilibrium heat flow, which in reality occurs only after 1 to 2 hours' exposure to constant surroundings. The physical and psychological response of people to changing thermal environments has been studied only for nude subjects in indoor laboratory conditions *(Gagge et al. 1967)*.

Model for heat loss to a cold outdoor environment

The following describes a model of thermal comfort used to assess the environmental quality of buildings in the cool San Francisco environment. Total heat loss from the body is the sum of dry heat loss (convective, radiative, and conductive) and insensible evaporation from skin and lungs. Evaporation is roughly independent of atmospheri humidity and represents a roughly constant 25 percent of the body's heat loss. It has not been possible to demonstrat any difference between the popular "we cold" and "dry cold." Conductive losse are low in pedestrians and are ignored The dry heat loss is thus defined as:

$$kQ = \frac{A_c}{A_{Du}} \left(\frac{T_b - T_a}{R_b + R_c + R_a} \right) + \frac{A_n}{A_{Du}} \left(\frac{T_b - T_a}{R_b + R_a} \right)$$

in which:

Q is total heat loss from body.

k is the fraction of non-evaporative he loss (0.75).

A_c and A_n are the surface areas of clot ing and exposed nude skin, respectivel A_{Du} is the DuBois total nude surfa area (see previous definition in secti on "Wind pressures in steady winds." T_b is body core temperature, normal 37° C.

T_a is mean radiant temperature, the a erage temperature of air and radiant surroundings.

R_b is the insulation of body tissues commonly assessed as 0.09 m^2 deg C/watt.

R_c is insulation of clothing itself.

$$R_a = \frac{1}{h_r + h_c} = \frac{1}{4.3 + 12u^{0.5}}$$

where h_r and h_c are the radiative and convective heat transfer coefficients; h_c has a minimum value of 4 watts/m^2 °C in still air.

Insulation of clothing is commonly given in "clo" units, equal to 0.155 m^2-°C/watt. Clothing insulation is usually quantified by measuring the power consumption of a dressed heated mannikin in still air and describing the resulting insulation as uniformly distributed over the entire body surface. Because this method does not allow for the disproportionate influence of wind on nude as opposed to clothed surfaces, the above formula treats the two surfaces as parallel heat losses. The value of R_c must be selected to represent the garments themselves. For example, 1 clo traditionally represents the insulation of a business suit distributed over the entire body, whereas the insulation over the clothed area itself is 1.2 clo.

Solar energy absorbed by the body counteracts heat loss. The incoming radiation's effectiveness in heating the body is proportional to the amounts of insulation within and without the point of absorption; i.e., solar heat gain Q_I is greater for nude than clothed surfaces:

$$\text{For nude, } Q_I = \frac{R_a}{R_b + R_a} I\ (1 - a)$$

$$\text{For clothed, } Q_I = \frac{R_a}{R_b + R_c + R_a} I\ (1 - a)$$

where $I\ (1 - a)$ = Absorbed solar radiation at the surface.

I = Total solar influx on the body surface, watts/m^2.

a = Reflectivity of clothing or skin, ranging from 0.8 for white clothing, 0.43 for white skin, to 0.16 for black clothes or skin.

If we let $I(1-a) = S$, then the net dry heat loss equals

$$kQ - Q_I = \frac{A_c}{A_{Du}} \left(\frac{T_b - T_a - SR_a}{R_b + R_c + R_a} \right) + \frac{A_n}{A_{Du}} \left(\frac{T_b - T_a - SR_a}{R_b + R_a} \right)$$

Solar radiation influx includes direct beam, diffuse sky, and reflected components. The proportions of the total body surface A_{Du} exposed to these streams have been calculated and measured *(Blum 1945)*. Body surface area exposed normally to the direct beam varies from 7 percent A_{Du} to 30 percent A_{Du} as the sun moves from the zenith to the horizon. In practice, the increased area exposed to low-altitude sun nearly compensates for the decreased intensity of the direct beam. One-half of A_{Du} is assumed to be exposed to the diffuse radiation from the sky vault and the other half to the radiation reflected from the ground. These exposure proportions of the total body surface are assumed to apply to the clothing and exposed skin surfaces as well. The sky and ground may be assumed to radiate at uniform intensities for the purposes of this model.

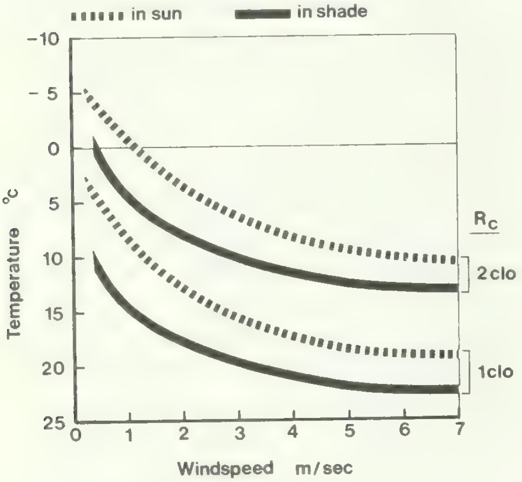
An equivalent treatment can be applied to longwave radiation gain or loss when the temperatures of surrounding surfaces are substantially different from air temperature. In these cases air temperatures would represent the surroundings and a is 0.05. The differences between the air and outdoor surface temperatures are usually too small to warrant this refinement.

Thermal balance exists when the net heat loss $(Q\text{-}Q_I)$ is equal to the metabolic heat production M (table 4). "Comfort curves" (fig. 3) can be drawn for heat loss versus wind and temperature for various sun and clothing levels.

Table 4.—Metabolic rates

Activity	Metabolic rate M/A_{Du}
	Watts/m²
Sleeping and digesting	47
Sitting quietly	59
Standing	71
Strolling—0.7 m/sec (1.5 mph)	107
Level walking—0.9 m/sec (2 mph)	116
Level walking—1.35 m/sec (3 mph)	150
Level walking—1.8 m/sec (4 mph)	220
Level walking—4.5 m/sec (10 mph)	590
Sprinting—10 m/sec (22 mph)	2,400

Figure 3.—Sample comfort curves for a range of temperature and windspeed. $M/A_{Du}=150$ watts/m², equivalent to walking 3 mph. Direct sun on horizontal surface=285 watts/m².



These have the following shortcomings:

1. They assume thermal equilibrium, which requires 1 to 2 hours' continuous exposure to the outside environment. This is rare for pedestrians.
2. They show no effect of wind penetration or infiltration of clothing. There is a serious lack of experimental data on clothing performance in wind.
3. Clothing resistance is not easily defined for any civilian population, due to the extreme variability of clothing worn at any time. The curves are sensitive to the chosen value of R_c.
4. There is virtually no experimental evidence describing how physiological heat loss influences the psychological perception of comfort outdoors.

DESIGN PROCESS

The designer should consider outdoor comfort early in his design. Because the relationship between the physical form of the design and the climate and comfort around it is often complex, he may have to follow a climatic design process in order to find a satisfactory solution. The process is basically to: (A) determine the climatic characteristics of the site and the preliminary project, partly by model tests; (B) assess its effects on outdoor comfort; and (C) modify the project design and test the climate and comfort again until a solution is reached.

PREDICTING THE LOCAL CLIMATE OF A SITE

Solar radiation and wind are the most important climate information for comfort prediction. Of the various climatic elements, these have the greatest variation across a site of architectural or planning scale. They are also the climati elements over which the designer ha most control. Elements with less sit variations and importance to comfor analysis are longwave radiation, ai temperature, and air humidity.

Solar Radiation

The important facts about sunligh are its duration and its intensity. Thes are influenced by both the geometric and meteorological nature of the si and its location.

Regional scale. — Daily possible sol duration is readily available in standa meteorological tables and is a geometr function of latitude. Solar duration further influenced by the meteorologic probability of sunlight or cloud. The data are readily available from t Weather Service as seasonal or hou values of percent cloudiness, percent possible sunshine, or number of ho of cloud.

Solar intensity is influenced by la

tude (atmospheric path length) and atmospheric turbidity. Solar intensity is not widely measured and, if available, is usually in the form of daily total energy per unit area.

A most useful method of obtaining average hourly solar intensities is given by Liu and Jordan *(1960)*, based on observed constancy between daily and hourly values in regions of equal atmospheric clarity.

Local Scale. — On the site itself, solar radiation is described by its extent and by the amount of time it is either on or off. The surrounding buildings either obstruct or admit light to the pedestrian areas. There is little variation in the intensity of direct sunlight in most outdoor spaces. Local exceptions might occur in places screened by thin vegetative canopies or near highly reflective surfaces.

Sunlit and shaded areas may be predicted from a model with a light source representing the sun. The daily sunlight characteristics of an existing site are conveniently determined by use of a oboscope or of fisheye photographs of the sky hemisphere overlain with appropriate sunpath diagrams. An excellent description of solar geometry prediction techniques for designers is given by Burberry *(1966)*.

A computer program has been developed at the Department of Architectural Science, University of Edinburgh, to integrate shadow areas over any period of day and present these shadow durations in contour form. We have not used this technique, although it could be useful in the eventual preparation of daily "comfort contours."

Wind

Regional scale. — Wind records are available for most locations; recording stations are commonly found at airports in open terrain. For most sites wind information must be extrapolated geographically from the recording station to the vicinity of the site. The effects of topography, vegetation, and structures must be carefully considered in this extrapolation. If possible, wind-recording equipment installed on site should be run synchronously with nearby weather stations for a suitable period of time to establish the relation between winds at the two locations. This is expensive and time-consuming, however.

The meteorological data base should provide information necessary to determine the amount of time that pedestrians will be uncomfortable on the site. This requires hourly wind data, preferably in conjunction with data on temperature and sun. The most useful wind summary is a cumulative frequency distribution providing the percentage of time that each wind velocity is exceeded for each wind direction. This data format is rarely available and must usually be calculated from the station's raw data.

Local scale. — Winds at pedestrian level will often be strongly affected by the building, planting, and grading configuration of the project. The wind patterns over the pedestrian areas of a site are far more difficult to predict than the presence or absence of sunlight. If a yet-unbuilt project seems likely to be windy, it should be tested in model form in a wind tunnel. This technique is also useful for defining winds on existing sites, since the flow strength, stability, and direction can be controlled during the tests. Physical modeling with limited field verification is most desirable.

Physical modeling requires the use of a specialized wind tunnel that reproduces the boundary-layer conditions above the actual site. Both the velocity and the turbulence intensity profiles should be modeled to scale. The most satisfactory means of achieving this at present is to generate the boundary layer with turbulence generators and long lengths of roughness similar to that of the terrain upstream of the project site.

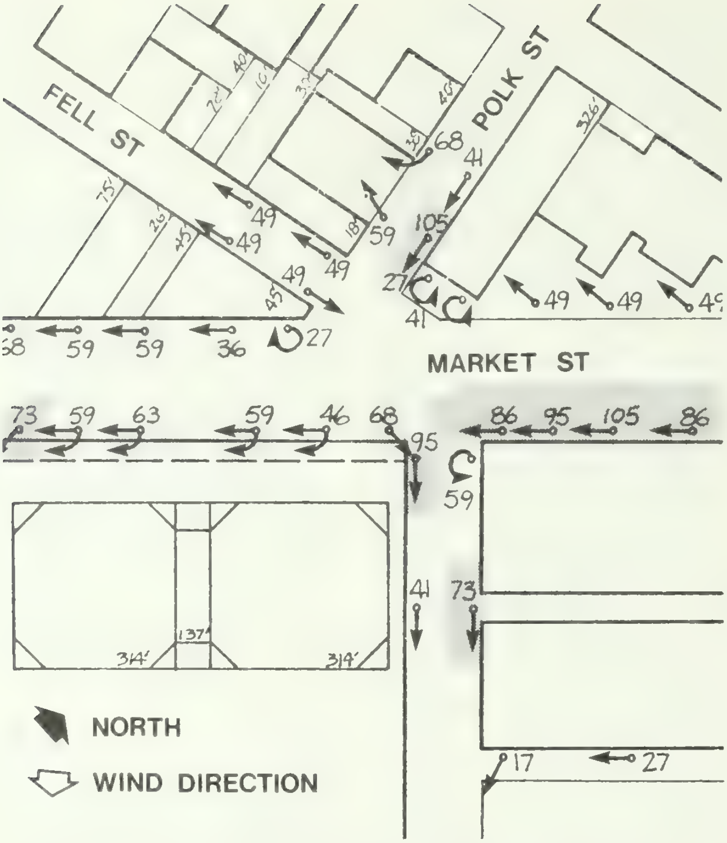


Figure 4.—Nondimensional wind speeds obtained from wind-tunnel tests of a scale model. Shading indicates areas of high wind speeds.

Wind speeds measured in the wind tunnel are nondimensionalized and are expressed as a percentage of a reference wind speed. The reference wind speed is that measured at the reference height, often chosen as the height of the wind instrumentation of the weather station providing climatological wind data. By relating wind-tunnel measurements to climatological data, wind-speed frequency distributions on the site are defined.

Measurements of wind speed are normally made at a network of grid points within and around the project model. A hot-wire anemometer is used to measure wind speed and turbulence at each grid point. Its small size allows it to measure within millimeters of the surface, representing pedestrian height a model scale. Separate tests are made fo each wind direction, the number of directions normally corresponding to th number of points of the compass considered in the meteorological wind dat base. An example of wind-tunnel dat for a downtown San Francisco site i given (fig. 4).

Temperature, Longwave Radiation, Humidity

Air temperature, longwave radiatio from the ground and atmosphere, an humidity are important heat-transf mechanisms; however, they vary litt across normal architectural sites.

Temperature. — At a regional scal one should consider microclimatic effec when extrapolating a regional air temperature value to the site. Temperature may be substantially modified by frost pockets and urban heat islands, for example. On the site itself the variation is usually much less.

Longwave radiation. — In comfort models, air temperature and the temperature of the surroundings are either assumed equal or averaged into a "mean radiant temperature" that is used as the ambient temperature. Since surface temperatures usually do not differ from air temperatures by more than a few degrees, the difference between longwave radiation contributed by the surfaces on site and that of surroundings at air temperature is very small. In light of the accuracy of the thermal model, calculation of surface temperatures and longwave radiation flux is not justified. In hot environments, where the thermal requirements for comfort are more closely quantified, local surface temperatures and radiation exchange are mportant design characteristics.

Humidity. — Humidity has no quantiied role in cold environment heat loss. In hot environments, humidity plays a ritical part in determining comfort.

ASSESSING COMFORT ON A SITE

The complicated interaction of climaic variables that determine comfort can e handled best statistically. A logical nd simple measure of comfort is the ercentage of time that comfort or discomfort will occur on a given day at a specific time. Care should be taken in selecting the proper season and time for the analysis of comfort so that the period of greatest use or sensitivity to scomfort is considered.

We have used two different criteria efining uncomfortable conditions in our analyses, based first on the thermal and hen on the mechanical effects of climate. he computation process for determining discomfort probability is different nder these two methods (fig. 5).

Thermal comfort prediction method

For each measurement point, the time of day, day of year, expected type of human activity, and expected level of clothing are specified. The average temperature for this period is then found.

The first step in the calculation involves defining the "discomfort threshold wind speed" from the comfort curves. Separate threshold values are defined for sunny and shady conditions. If the point of interest is shaded by structures or topography, the calculations need only consider the sunless case. If it is in the sunshine, separate calculations must be made for the sunny and shady cases.

The nondimensional wind speeds obtained in the wind tunnel are then used to specify the reference wind speed corresponding to the threshold wind speed on the site for each wind direction; i.e., the threshold wind speed is divided by the nondimensional wind speed.

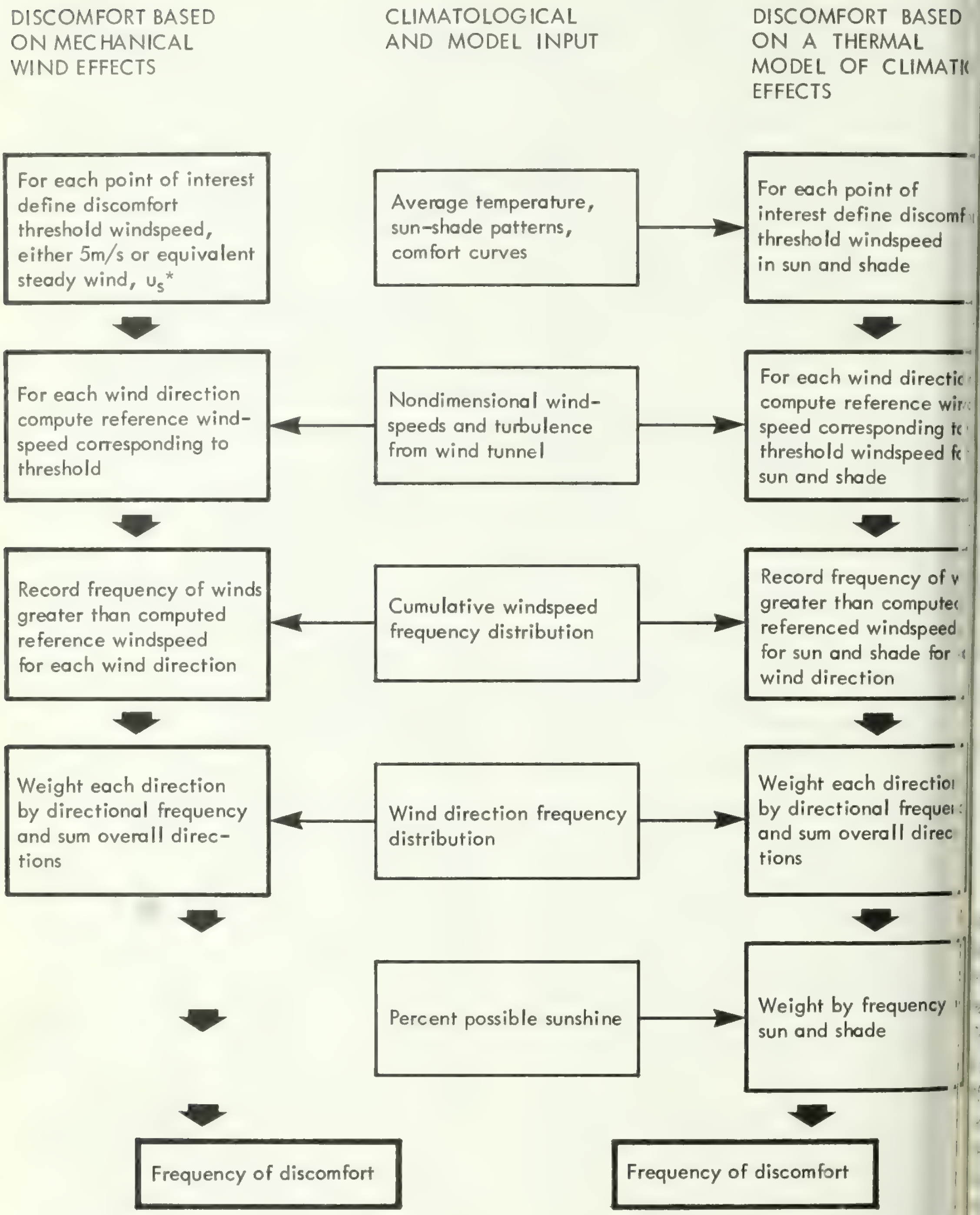
The frequency of reference winds exceeding the specified level is then obtained from cumulative wind-speed frequency curves, again separately for each wind direction and for the sun and shade cases.

The result is the probability of discomfort occurring during wind from each direction. These probabilities are then weighted by the probability of each wind direction's occurrence. For a point in the sun, two separate discomfort probabilities are calculated. They are then weighted by the climatological probabilities of sunshine and clouds and combined into a single probability.

Calculated discomfort frequencies for a downtown San Francisco site are shown as an example (fig. 6). The clothing level chosen is light but corresponds to our estimate of average men's and women's clothing at this time of year.

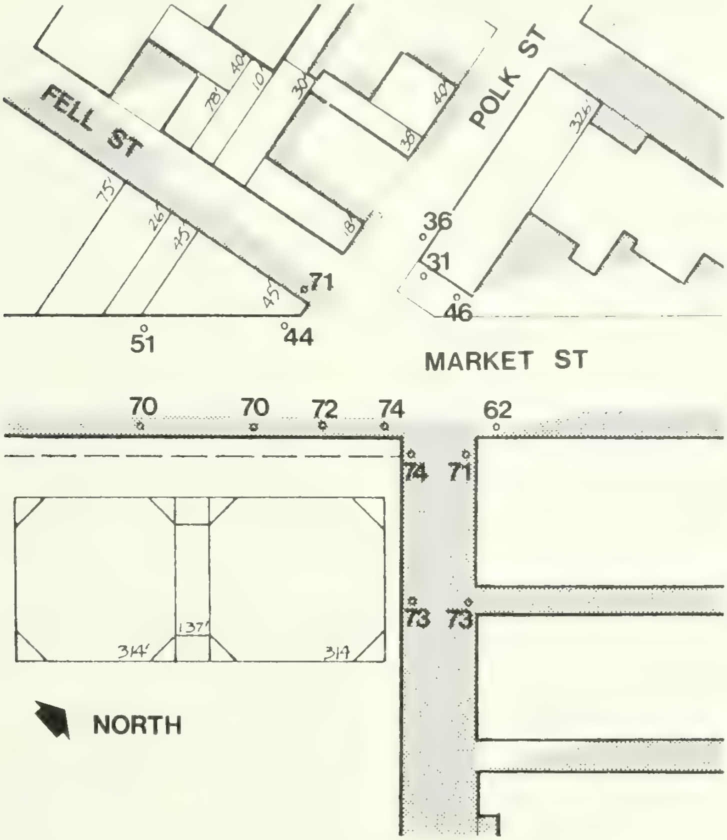
The pattern of discomfort frequency seems reasonable in that shaded areas exhibit a much higher discomfort frequency than areas in the sun. The absolute values, however, are extremely high, especially in the shaded areas. The

Figure 5.—Calculation process in determining discomfort frequency.


DISCOMFORT BASED ON MECHANICAL WIND EFFECTS
CLIMATOLOGICAL AND MODEL INPUT
DISCOMFORT BASED ON A THERMAL MODEL OF CLIMATI EFFECTS
For each point of interest define discomfort threshold windspeed, either 5m/s or equivalent steady wind, u_s*
Average temperature, sun-shade patterns, comfort curves
For each point of interest define discomf threshold windspeed in sun and shade
For each wind direction compute reference windspeed corresponding to threshold
Nondimensional windspeeds and turbulence from wind tunnel
For each wind directic compute reference wir speed corresponding to threshold windspeed fc sun and shade
Record frequency of winds greater than computed reference windspeed for each wind direction
Cumulative windspeed frequency distribution
Record frequency of w greater than computec referenced windspeed for sun and shade for wind direction
Weight each direction by directional frequency and sum overall directions
Wind direction frequency distribution
Weight each directio by directional freque and sum overall direc tions
Percent possible sunshine
Weight by frequency sun and shade
Frequency of discomfort
Frequency of discomfort

*See Table 2

Figure 6.—Frequency of discomfort based on thermal influence of climate. The analysis is for the first day of spring at 1 p.m. with a temperature of 15°C (61°F). The discomfort frequencies are for a person walking 3 miles per hour, wearing clothing with $R_C=1$ clo, averaged as 0.8 clo over the entire body.



uniformity of the frequencies within the shaded areas is unexpected considering the variation of windspeeds over these areas.

The explanation of these discrepancies lies in the assumptions of the thermal comfort model. As a steady-state model, a period on the order of 1 hour is required for a person to come to thermal equilibrium with the environment. The average duration of a pedestrian trip is more on the order of 5 to 10 minutes, however, so that the steady-state conditions would never be reached.

Applying the steady-state model to a transient situation underestimates the discomfort threshold wind speed. In shady areas the model is so oversensitive to wind that almost any wind will cause discomfort, resulting in discomfort frequencies uniformly approaching the climatological probability of non-calm winds.

While providing poor estimates of comfort in pedestrian areas, the thermal model may be useful in other applications. The assumptions of the model apply to outdoor sports arenas and theaters, picnic areas, and beaches; and the model could provide usable discomfort estimates for such areas.

Comfort prediction method based on mechanical wind effects

The inaccuracies of the steady-state thermal model are avoided by basing comfort prediction on mechanical effects of the wind alone. The computational requirements of this method are also far less. The mechanical method will, of course, underestimate the discomfort frequency by neglecting discomfort caused by thermal cooling.

In the computation (fig. 5) the discomfort threshold speed is now set at 5 meters/second (11 miles per hour), regardless of temperature or sunshine. If turbulence is considered, the equivalent steady windspeed u_s is calculated for each point of interest and used as the discomfort criterion (table 2). The remaining steps are similar to those in the thermal prediction method, except that sun-shade effects are ignored.

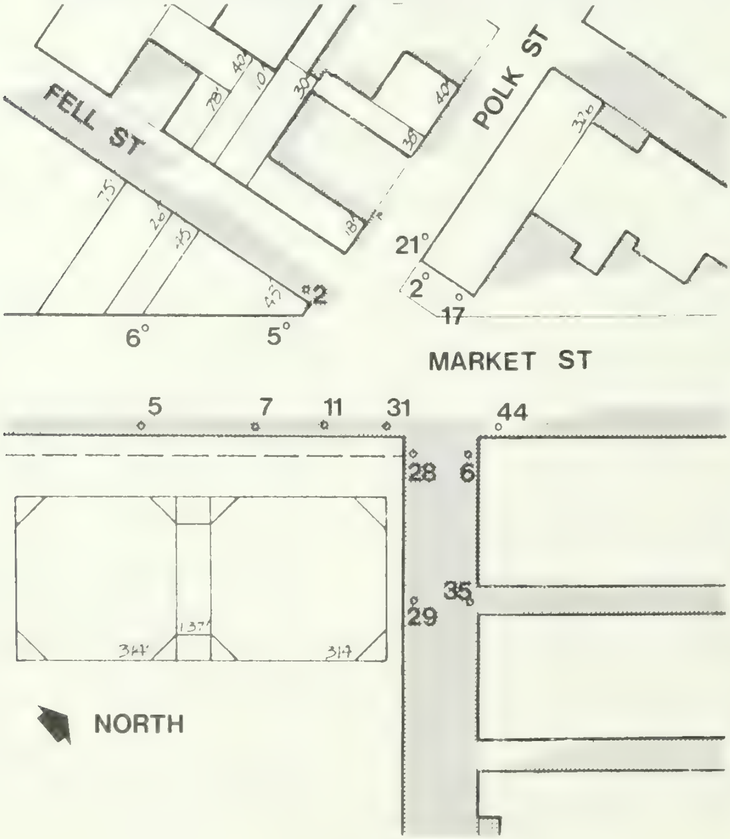
Discomfort frequencies calculated by using mechanical wind effects criteria are lower than those calculated by thermal prediction (fig. 7). There is also considerably more variation over the site, reflecting the varying strengths o the wind.

While ignoring temperature and sun-shade effects, the mechanical metho provides a reasonable estimate of discomfort due to wind. Although the absolute values are known to be low, the pattern and relative values are bot reasonable and useful. Sun-shade plots are included in the analysis to provide an intuitive judgment of thermal comfort as well.

IMPROVING SITE COMFORT

The comfort-prediction process described above estimates the levels of comfort to be expected at a site ar

Figure 7.—Frequency of discomfort based on mechanical influences of wind, for same conditions as figure 6.



points out problem areas. This information can be used to design and locate building entrances, walkways, plazas, and balconies, as well as parks and recreational facilities. If the expected comfort levels are unacceptable, design modifications to improve conditions may be investigated.

Based on trials with wind tunnel models, design modifications within the site and budgetary limitations of the project are suggested. These modifications can range from changes in building height, bulk, or orientation to the provision of vegetation or landscaping to reduce winds.

For any given problem there is a range of possible solutions varying in effectiveness and cost. The procedures described in this paper may help optimize these factors. For example, roofing over a shopping mall would surely reduce winds, but construction of wind deflectors or latticework or use of vegetation may yield the same results at far less cost. The influence of such devices n sunlight should also be considered.

A model of the modified design is ested in the wind tunnel and the analysis of comfort repeated. Further modications are again suggested and the rocess is repeated until a satisfactory esign is obtained.

CONCLUSIONS

Prediction of discomfort frequency at planned urban site is possible by using ind-tunnel tests of scale models to redict winds. There is insufficient nowledge at present to base discomfort requencies on the thermal effects of limate. A simple prediction method, ased on the better-understood mechanical effects of wind, yields results that re useful in the layout, orientation, and esign of a project. This method provides a rationale and criteria for design modifications to improve outdoor omfort.

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Human Thermal Comfort in Urban Outdoor Spaces

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ABSTRACT.—Measurements of the physical environment of urban open spaces in Syracuse, New York, were used to compute the physiological responses of human users of the spaces. These calculations were then used to determine what environmental variables were both important to human comfort and susceptible to control by site design. Although air temperature and humidity are important to human thermal comfort, these variables were found not to be related in any way to site features; temperature and humidity in the central business district were uniform over space. The other variables found to be important to human thermal comfort are, in order of importance: solar radiation, infrared radiation, and wind speed. We found that all of these can be controlled to some extent by site design. Thus site design can be used to control human thermal comfort in outdoor urban spaces.

THE SUCCESS of an urban open space is influenced by many factors. The myriad components of the physical and social environment and the location of the space within the structure of the city all play primary roles. In this paper we focus on just one aspect of the physical environment: the thermal environment. We define the thermal environment as those physical-environment elements which determine human thermal comfort. This comfort is controlled by the energy exchange between the body and its surroundings and, in general, can be said to exist when the body can effortlessly maintain a constant deep body temperature of about 98.6°F. Thus the thermal environment consists of elements which determine heat exchange between the body and its surroundings: solar and infrared radiation, temperature and humidity of the air, and wind velocity. Of course, the activity of the person also plays a role, since as activity increases so does metabolic heat production.

The purpose of this study was to determine how various physical features of urban open spaces were related to human thermal comfort through their influence on the environmental elements. The basic question was "What features of the thermal environment, and hence human thermal comfort, are susceptable to control by site design?" Our study was a prelude to the development of design guidelines, some of which appear elsewhere in these proceedings *(Plumley)*.

METHODS

The experimental design of our study centered around the determination of human thermal comfort in various urban open spaces with different features. The role of various site features was determined from the study of their influence on the variables which determine thermal comfort. Comfort was determined by means of a model of the physiological response of humans to the environmental conditions as measured at each site. Psychological comfort could then be inferred from the predicted physiological state.

Human Thermal Comfort

Thermal comfort is a psychological interpretation of the physiological state of the body and should not be confused with temperature sensation. Gagge *(1969)* summarized comfort and temperature sensation as follows:

1. For sitting, resting persons:
    a. A sense of neutrality, of comfort or pleasantness, always coincides with a state of thermal neutrality (maintenance of deep-body temperature at 98.6°F without regulatory effort via vascular constriction or dilation or sweating).
    b. Discomfort correlates best with skin temperature in cold conditions and with increased skin sweating in hot conditions.
    c. Temperature and comfort sensations do not behave the same way with changing environment. Temperature sensation changes more rapidly than comfort sensation and, cold discomfort changes more rapidly than does warm discomfort.
2. Under conditions where the subject is active the following changes in sensation occur:
    a. Temperature sensation in warm and cold conditions is best correlated with skin temperature and air temperature and is *not affected by the level of activity.*
    b. Warm discomfort is best correlated with increased skin sweating.

It is evident that skin temperature and sweating are the important sensible physiological reactions of the body to a thermal stress. Thermal stress is created when the net loss of thermal energy from the subject's body does not equal the production of heat by metabolism within the body. In order for deep body temperature to remain constant, this balance of heat losses and gains must be obtained. Under cold conditions the losses usually exceed the gains, and several physiological systems act to reduce heat loss from the body. Vascular constriction reduces blood flow to the skin, and, as a result, skin temperatures drop. Heat production can be increased by voluntary activity or by involuntary shivering. Under warm conditions the body is gaining more heat than it can dispose of without effort, and vascular dilation occurs, with the result that the skin warms. If this action is insufficient to balance the heat budget, then sweating will occur. If the sweat rate exceeds the ability of the environment to evaporate the moisture, the skin will become wet.

The exchange of heat between the body and the environment can take place in several ways (table 1). For each heat-flow route, we have listed the controlling environmental factors and the conditions which determine whether the flow of heat in the route is toward (source) or away (sink) from the body. To actually predict the thermal state of the body in any given situation, equations must be written for each of these routes, and the set of simultaneous equations which results must be solved for the condition of interest: skin temperature and/or skin wettedness.

We have used a relatively old model of physiological response developed by Belding and Hatch *(1955)* and improved by Lee and Henschel *(1963)*. This model computes a Relative Strain (RS) for any given environmental condition and level of activity. Lee and Henschel *(1963)* related the various levels of RS to psychological conditions of "comfort," "discomfort," "failure," etc. However, since all of these correlations have been developed for subjects *indoors,* caution must be taken in applying these comfort ranges to people outside.

The Relative Strain model is:

$$RS = \frac{\text{Evap. cooling required to maintain heat balance}}{\text{Maximum evap. cooling possible under existing conditions.}}$$

$$= \frac{M\ (I_2 + I_c) + 5.55\ (T_a - 35) + RI_a}{7.55\ (44 - P_a)}$$

where

M = metabolic rate Kcal $M^{-2}hr^{-1}$
I_a = insulation of air clo
I_c = insulation of clothing clo
T_a = air temperature C
R = radiant load Kcal $M^{-2}hr^{-1}$
P_a = vapor pressure of air mm Hg

and

$$\ln I_a = 0.5662 + 0.4026 \ln U + 0.0072 \ln U^2$$

U = wind speed mph

Radiant Loads (infrared and solar) are included by adding the energy absorbed to metabolism. This model wa incorporated into an interactive computer program which computed RS from the environmental data gathered in each site. Table 2 shows the psychologica response in terms of RS.

Site Selection

Figure 1 shows the Syracuse downtown area and the general location o the eight sites used by Vittum *(1974)*. For this report we will be discussin

Table 1.—Summary of heat flow between a body and its environment

Heat-flow route	Controlling environmental elements	Conditions for route being —	
		Source	Sink
Metabolism	Activity of subject	Always	——
Radiation			
Solar	Shade-producing elements	Daytime	——
Infrared	T_r, T_s	$T_r > T_s$	$T_r < T_s$
Convection	T_a, T_s, w	$T_a > T_s$	$T_a < T_s$
		(increasing with increasing w)	
Evaporation	P_s, P_a, w	——	$P_a < P_s$
		(increasing with w)	

T_s = Skin (clothing) temperature.
T_r = Radiant temperature of surroundings.
T_a = Temperature of the air.
w = Wind speed.
P_s = Vapor pressure of skin ($f(T_s)$.
P_a = Vapor pressure of air ($f(T_a$, RH).
RH = Relative humidity.

Table 2.—Interpretations of physiological responses to relative strain for the standard man (Lee and Henschel 1963, p. 24).

Relative strain	Physiological effects for the standard man
0—0.2	100 percent of individuals comfortable.
0.25	50 percent of individuals comfortable.
0.30	100 percent of individuals uncomfortable.
0.30—0.40	75 percent of individuals show stress.
0.40+	100 percent of individuals show distress.
0.40—0.50	50 percent of individuals show signs of physiological failure.
0.50—0.60	100 percent of individuals show signs of physiological failure.
0.60+	Responses approach or exceed range within which system experiences breakdown.

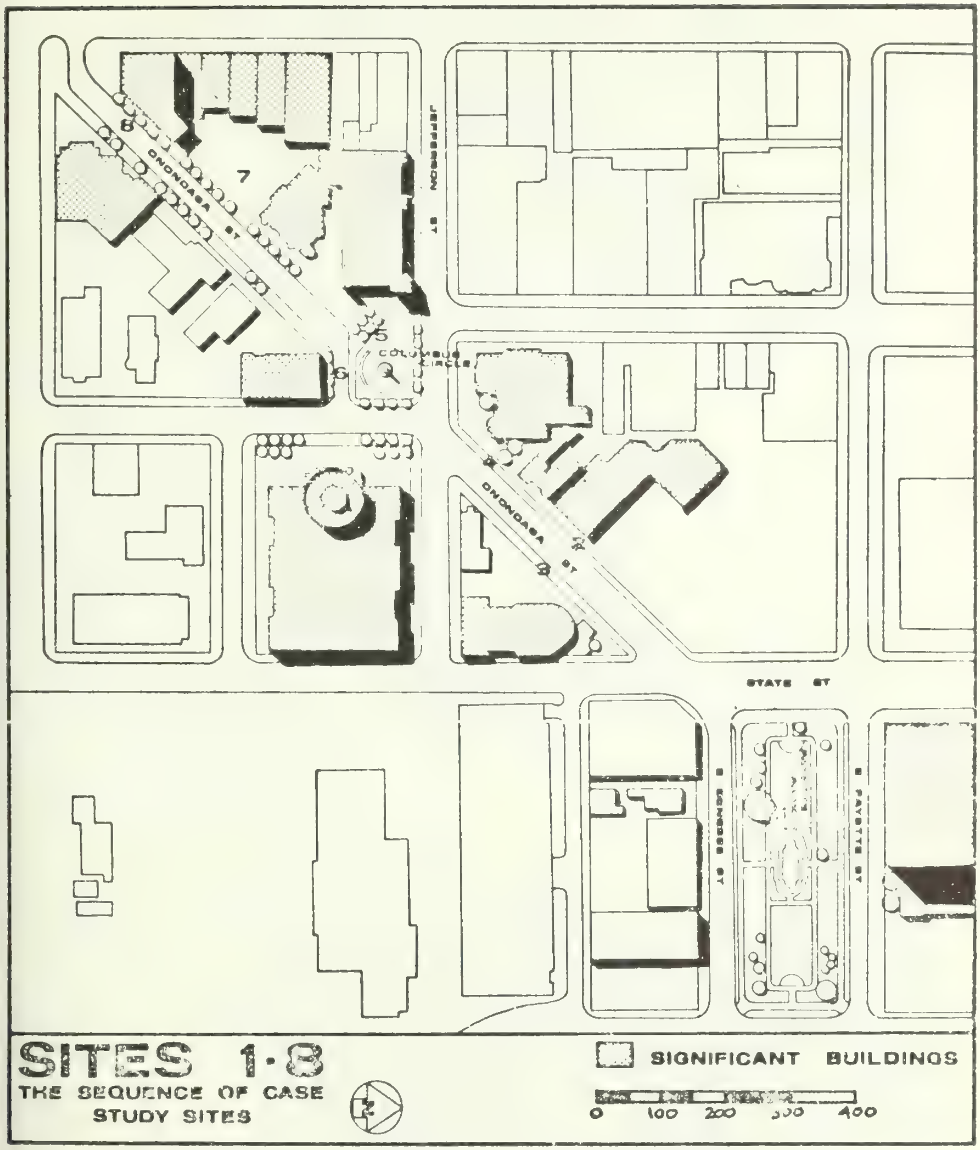

Figure 1.—Plan of the study site, showing the location of sites 1 to 8 as well as the significant buildings.

oly four sites (1, 2, 6, and 7), which ae shown in figures 2, 3, 4, and 5.

Site 1 is located in a park with very litle enclosure, since most of the surrunding buildings are only two to three sries high. The ground surface at the se is grass. Table 3, which lists the vw factors for the predominant surfes at each site, shows that the surfes as seen by a person at this site are nrly evenly split between sky and gss. Site 2, located on the sidewalk in a fairly open space on Onondaga Street, has nearly the same view of the sky and ground, but the ground surface is primarily concrete. Site 6, located on the north side of a building within Columbus Circle has a relatively low view of the sky since the site is more enclosed, as indicated by the high view factors for the surrounding buildings and trees. The ground surfaces are brick and asphalt. Site 7 has a high view of the sky, and the ground surface is

Figure 2.—Site 1. 'X' marks point where measurements were taken and for which view factors were calculated.

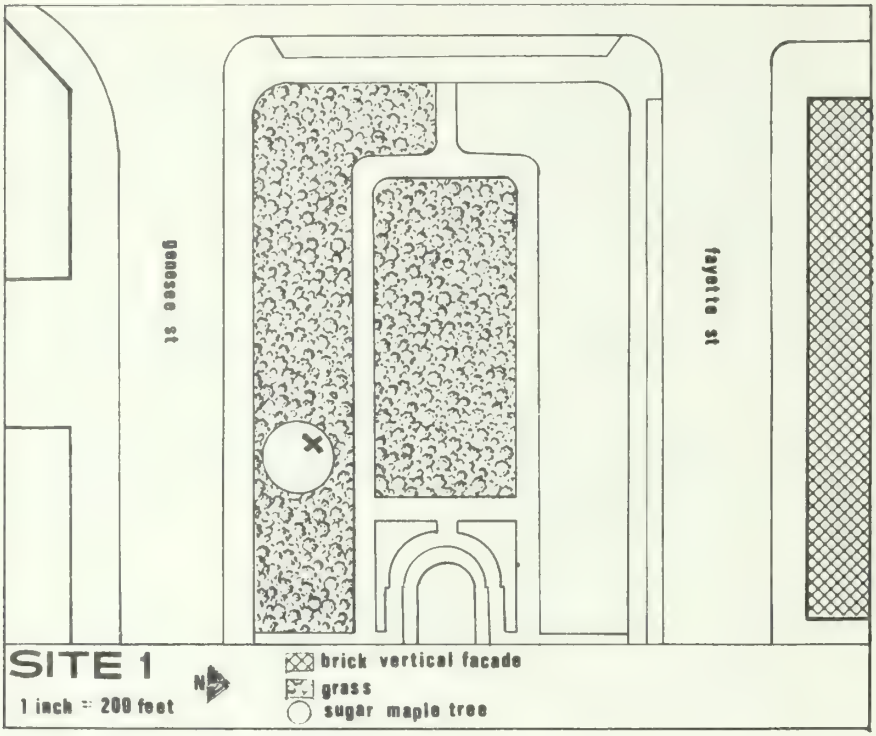

Figure 3.—Site 2.

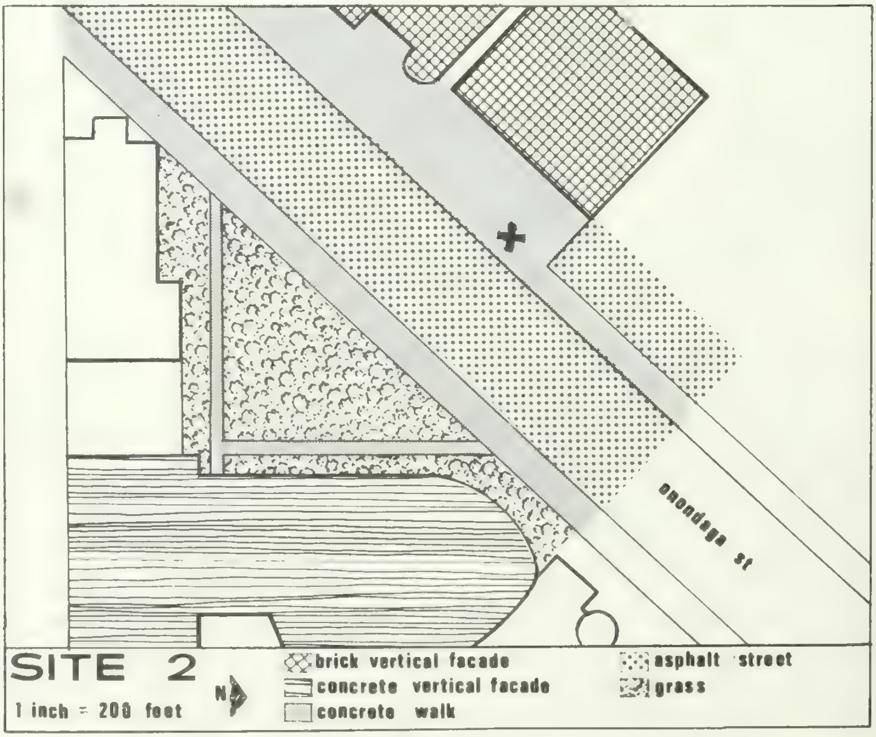

Figure 4.—Site 6.

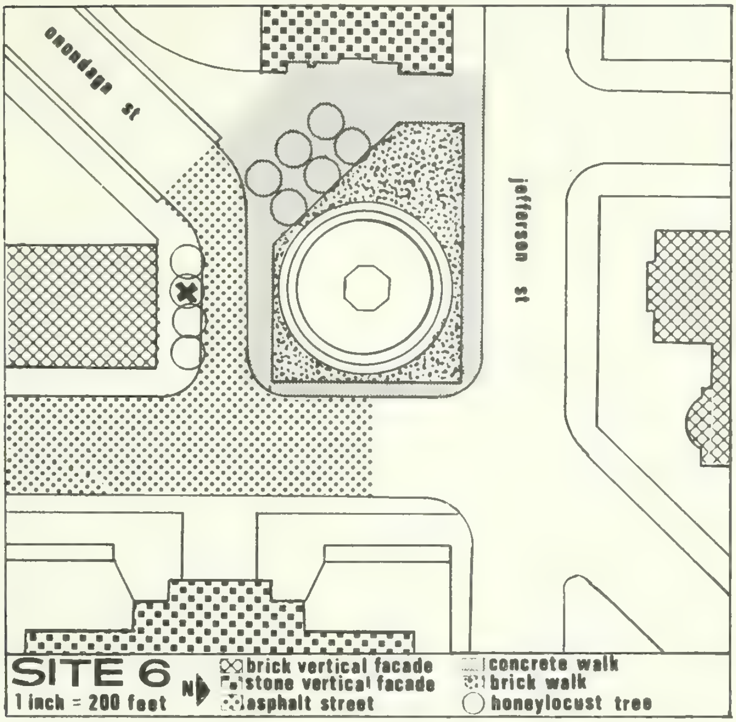

Figure 5.—Site 7.

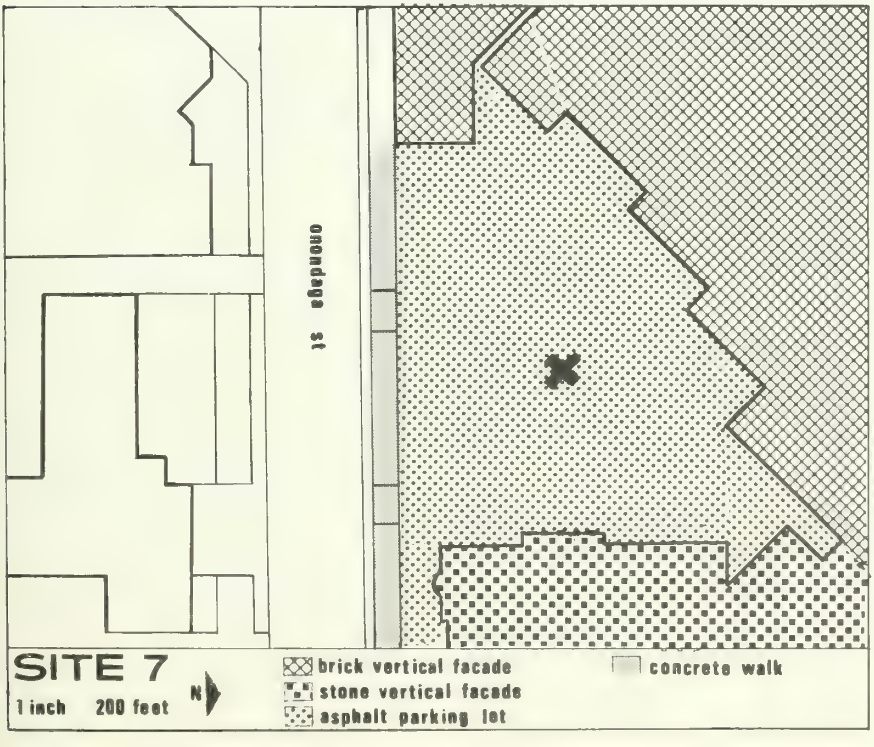

Table 3.—View factors between subject standing at site location and surrounding surfaces.

Site No.	Surfaces									
	Sky	Street	Walks		Tree(s)	Grass	Building Facing			
			Brick	Concrete			N	E	S	W
1	39	—	—	—	7	50	4	—	—	—
2	38	4	—	42	—	—	—	10	—	5
6	14	8	34	—	10	—	21	7	1	4
7	36	50	—	—	—	—	—	2	5	6

primarily macadam. Vegetation is a feature only in site 6, which is located beneath a row of street trees.

Environmental Measurements

A portable instrument system was used to measure air temperature and humidity, solar radiation, and wind speed at each site. The radiant load was computed from the measured solar radiation and from knowledge of the sun's position in the sky at the time of measurement. The infrared load was computed from view factors, and surface temperatures were measured with a radiation thermometer. The view factor is the proportion of the total spherical field of view from a subject taken up by the surface or object of interest. The infrared exchange between the subject and the surface is proportional to the view factor and the difference in temperature between the subject and the surface (table 3).

RESULTS AND DISCUSSION

Table 4 lists environmental and comfort data typical of the four sites at three times of day: morning, noon, and evening.

The air temperature and humidity data for each measurement period show a surprising uniformity once the trend in temperature caused by the time it took to move from site to site is removed. Note that temperatures are increasing with site sequence in the morning and decreasing with site sequence in the evening. This uniformity of temperature prompted us to investigate further the uniformity of temperature within the Syracuse CBD. This was done simply by moving around very quickly with a single psychrometer (Bendix Psychron). This procedure indicated that the temperature at any given spot could vary by as much as 6°F in a short time due to changes in solar radiation caused by clouds. However, these changes took place over a large area; and moving from tree shade, to sun lit areas, to building shade showed that the temperature is not an element of open-space environment that can be controlled or moderated by site design. The same pattern was true for relative humidity.

Solar radiation showed considerable variation from site to site. Comparison of the radiation figures in table 4 with the maps of the sites shows that the variation in solar radiation is due primarily to shading by buildings or vegetation.

The IR radiation load, as listed in table 4 or as expressed as the mean radiant temperature (MRT) of the space obviously varies with the time of day. During the day site 7, which was located in an open macadam parking lot, showed the highest IR load (MRT) because of the high view factor between the person and the blacktop surface (table 3). No shade is provided by buildings or vegetation. Site 1, in the open grassy park, shows the lowest IR radiant load, again due primarily to the nature of the surface; grass in this case. Sites 2 and 6, both street sites, tend to behave in a similar way in relation to infrared radi-

Table 4.—Summary of environmental conditions and relative strains

Variable	0800—23 Aug 1973				1300—10 Sept 1973				2130—22 Aug 1973			
	1	2	6	7	1	2	6	7	1	2	6	7
Dry bulb temp. (°C)	15	16	17	18	22	24	24	24	15	15	15	13
Relative humidity (%)	65	63	60	59	41	35	36	37	73	67	75	77
Solar radiation $\left(\frac{\text{Kcal}}{\text{M}^2\text{hr}}\right)$	444	168	84	360	84	648	96	600	—	—	—	—
IR radiation	-51	-58	-55	-32	-69	-32	-35	-10	-98	-82	-71	-87
Wind speed (mph)	1.8	2.1	3.4	2.1	2.7	1.4	1.8	1.7	1.9	2.1	2.3	1.5
Relative strain	- 0.26	- 0.30	- 0.28	- 0.22	- 0.18	- 0.01	- 0.11	- 0.02	- 0.36	- 0.33	- 0.35	- 0.38
w/wind = zero	- 0.23	- 0.26	- 0.25	- 0.18	- 0.16	- 0.01	- 0.10	- 0.01	- 0.36	- 0.32	- 0.34	- 0.38
w/solar = zero	- 0.30	- 0.30	- 0.28	- 0.25	- 0.18	- 0.11	- 0.12	- 0.10	- 0.36	- 0.33	- 0.35	- 0.38
w/IR = zero	- 0.20	- 0.20	- 0.25	- 0.20	- 0.14	- 0.02	- 0.08	- 0.02	- 0.30	- 0.27	- 0.31	- 0.31
Mean radiant temperature (°C)	20	19	19	24	16	24	23	30	10	13	16	15
Weather condition	Partly cloudy, cool, breezy				Clear, cool, breezy				Clear, cool, breezy			
Sky temperature	18				5				5			

ation. According to table 3, site 6 "sees" considerably less sky, which on these days had an apparent radiant temperature of about 5 to 8°C, than site 7. Therefore it is not surprising that the infrared load in site 7 is more negative (MRT is lower) than in site 6.

Wind speed was variable over both site and time. The urban surface wind tends to be gusty but with a low average velocity. Wind speeds greater than 8 mph were rare. Wind direction was also variable and did not seem to be strongly related to the wind direction above the buildings as indicated by flags.

The lower part of table 4 lists relative strain as calculated for each site by using the environmental variables listed and also the relative strain which would occur if (1) the wind speed were reduced to zero, (2) the solar radiation were reduced to zero, and (3) the infrared radiation load were reduced to zero. These manipulations allowed us to determine the relative importance of the variables. Air temperature and humidity were not modified since they had already been shown to be inalterable by design.

Since the relative strains are all negative, we are dealing with a cool situation; the body requires more heat to achieve balance between inputs and outputs of thermal energy. Unfortunately we do not have any data relating the negative physiological strain to the psychological measure of comfort. However, we do know that to conserve heat the body will constrict the vascular system of the skin with the result that skin temperature is lowered. As mentioned above, cool discomfort is directly related to skin temperature, and the sensation of cool discomfort changes more rapidly below the neutral skin temperature (comfort condition) than above that point. Since we know that on the warm side, relative strain values of between 0 and 0.2 are "comfortable," and that discomfort increases with increasing relative strain (table 2), we can safely assume that the same will occur below thermal neutrality. In other words, we can use table 3 with absolute values of relative strain for a rough indication of comfort.

Wind speed had relatively little effect on relative strain (RS). The average change in relative strain when wind was reduced to zero was only 0.02 or about 10 percent of the RS value. The effect of wind does increase in magnitude with increasing strain, however: compare site 7, 0800 and site 2, 1300.

The effects of solar radiation are quite large as can be seen by comparing sites 1 and 2 at 0800 (RS of —.26 and —.30 respectively) and by studying the difference in relative strain when solar radiation is eliminated (see site 1, 0800; site 2, 1300; site 7, 1300 for example). The presence or absence of solar radiation has a strong influence on human thermal comfort.

At all sites the infrared radiation balance was negative; that is, heat is flowing away from the body, because all surfaces have temperatures below 30°C (skin/clothing temperature). Sites which have large view factors with sky will tend to have larger negative infrared radiation balances since the sky is usually cold, particularly on clear days. Thus sites 1 and 7 show a strong improvement in relative strain when the infrared radiation balance is reduced to zero. On the other hand, site 6, which has only 16 percent of its view occupied by sky (table 3) shows little change when the infrared balance is reduced to zero. Note that as the apparent sky temperature decreases, the effect of eliminating the infrared heat balance increases.

CONCLUSIONS

These data indicate that solar radiation, infrared radiation, and wind are important to human thermal comfort in urban outdoor spaces and, further, that they can be controlled through site design. Trees and other vegetation can be used to provide shade during hot periods to reduce the input of solar energy to the user's body. If spaces are used during cooler periods, then shading should be kept to a minimum. Structures, of course, can be used for the same purpose. Vegetation can be used to screen the user from sources of infrared radiation such as sun-heated walls and streets during the warm season and to limit infrared radiation loss to cold surface such as the sky during cold periods. Although it is not very important in the city under warm conditions, wind speed can play an important role during the cold season as is indicated by the popularity of wind-chill factors in winter weather reports. Various arrangements of vegetation and structure which could be used to reduce the heat losses due to high winds in winter would have little effect on RS in summer.

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Effect of Synthetic Surfaces and Vegetation in Urban Areas on Human Energy Balance and Comfort

by THOMAS F. STARK *and* DAVID R. MILLER, *graduate assistant and assistant professor of natural resources, The University of Connecticut, Storrs, Conn. 06268. This research was supported in part by funds provided by the Northeastern Forest Experiment Station through the Pinchot Institute for Environmental Forestry Studies.*

ABSTRACT.—The thermal balance of a standard man was quantified for a variety of urban and rural summer daytime microclimates. The resulting net heat-load data were correlated with the relative amounts of vegetation and synthetic materials at each site. By extrapolating these results, it is possible to estimate the expected heat load of a proposed development before it is built.

THERE IS LITTLE DOUBT that the day-to-day weather as well as the verall climatic pattern in an area af-ect which activities people pursue, how vell they perform, and generally whether hey feel comfortable *(Huntington and ushing 1924)*. Recently Belding and latch *(1955)* and Tromp *(1966)* def-nitely linked climatic variables with uman comfort when they observed that limatic parameters such as air tem-erature, humidity, and wind speed ause distinct and repeatable human hysiological stress responses.

The objective of our study was to xamine and quantify the thermal ex-canges between a theoretical subject ad several urban- and suburban-type stes to determine which were the most ad least comfortable and why. From te results, specific factors of site de-sgn that significantly affect human cmfort can be identified and utilized b city planners for future development.

DETERMINING HUMAN THERMAL COMFORT

Inequalities in the temperatures of terestrial objects results in an ex-chnge of energy between the objects as they approach thermal equilibrium wh each other. The major means by which energy is exchanged are radiation (R), convection (C), conduction (G), and the evaporation or condensation of water (LE). Over a sufficiently long period of time, the summation of all the energy gains and losses by an object or human subject will equal zero:

$$R+C+G+LE=0 \qquad [1]$$

The instantaneous rate of heat gain or loss, which must be compensated for to maintain the body core-temperature constant, has been established as an important factor in human comfort. But quantification of the instantaneous net heat load for human subjects is complicated by the facts that each of the processes of equation 1 act in not one but several ways and that clothing alters the exchanges in a variety of ways. Fanger *(1970)* presented a similar model for a human subject that demonstrates how a single process such as evaporation is complicated in the human energy balance problem:

$$M+R+G+G+Ed+E_{sw}+E_{re}+L+C=0 \qquad [2]$$

where:

M = Metabolic heat production.
Ed = Heat loss by skin diffusion.
E_{sw} = Heat loss by evaporation of sensible sweat .
E_{re} = Latent respiratory heat loss.
L = Dry respiratory heat loss.

In equation 2 the single evaporation term of equation 1 (LE) has been broken into three separate terms (Ed, E_{sw}, and E_{re}), each representing a form of energy exchange by evaporation that must be determined independently.

Before this relationship was derived, the rates of energy gain and loss, which determined the limits of the comfort zone, were established by asking a sample of people how they felt in a series of test environments. Those environments in which subjects most frequently said they were comfortable were then designated as comfortable; and upper and lower limits were established. Belding and Hatch *(1955)* then evaluated these limits, using a relationship similar to equation 2; and they concluded that the limits of the human comfort zone are ±500 calories per minute for an average subject.

MATERIALS AND METHODS

Data Collected and Site Description

Data were taken in June and July 1974 on The University of Connecticut campus at Storrs (latitude 41°47′30″, longitude 72°14′33″W, average elevation 215 meters). The University campus represents an urban-like environment built to be esthetically pleasing and surrounded by undeveloped woodlands. Eight sites that were felt to be microclimatically dissimilar were selected. Figures 1 through 7 are photographs and scale drawings that cover full 360° views of these sites.

Site 1 is not pictured, but is a typical area beneath the canopy of a 20-m-tall black oak *(Quercus velutina)* forest with moderate undergrowth.

At each site wet and dry bulb temperatures were measured with a Bendix aspirated psychrometer, wind speed with a Hasting's omnidirectional air meter, and surface temperatures of facing solids with a Barnes PR-10 infrared thermometer. Solar radiation was monitored with a Kipp pyranometer located in the northwest corner of site 2.

Data were taken at each site once every 2 hours of each data day beginning at site 1 and progressing sequentially through site 8. At the end of each run, measurements were repeated at site 2 to give some indication of how conditions had changed during the course of the data collection. Data runs were begun at 0730, 0930, 1130, 1330, 1530, and 1730 solar time. Transit time from site to site was approximately 3 minutes, and the total time elapsed from the start to the finish of a data run averaged 1 hour. A total of 8 data days were obtained for use in later analysis.

Data Reduction

Equation 2 was modified by splitting the radiation term into a solar radiation component (S) and an infrared radiation component (IR). The solar component was then evaluated, using the techniques of Underwood and Ward *(1966)*, giving the working model:

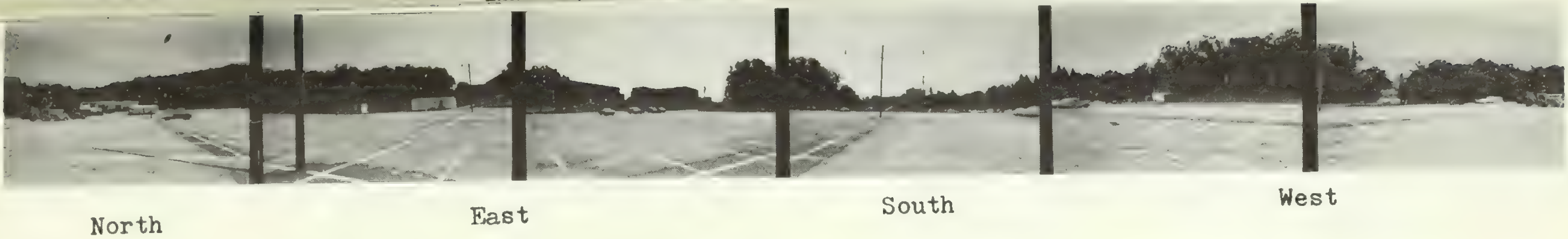
$$S-(r+t)\ S+M+IR+G+Ed+E_{sw}+E_{re}+L+C=0 \qquad [3]$$

where:

r = the reflectivity of the subject to solar radiation.

t = the transmissivity of the subject to solar radiation.

To quantify equation 3 and utilize it to compare the sites it was necessary to make a number of assumptions to rule out the variability between human subjects. For this study, the subject was assumed to be a young male, aged 20 to 35 years, with a surface area of 1.8 m^2 who was walking at 1.5 m sec^{-1} and whose orientation with respect to the sun was constantly changing. His skin temperature was assumed, from the basi of a literature review, as 32°C. A corresponding clothing temperature of 35°C was established from supplementary experimentation in which the actual temperature differences between the ski and outer clothing surfaces were mon tored and found to average 3°C. Cor


North
East
South
West

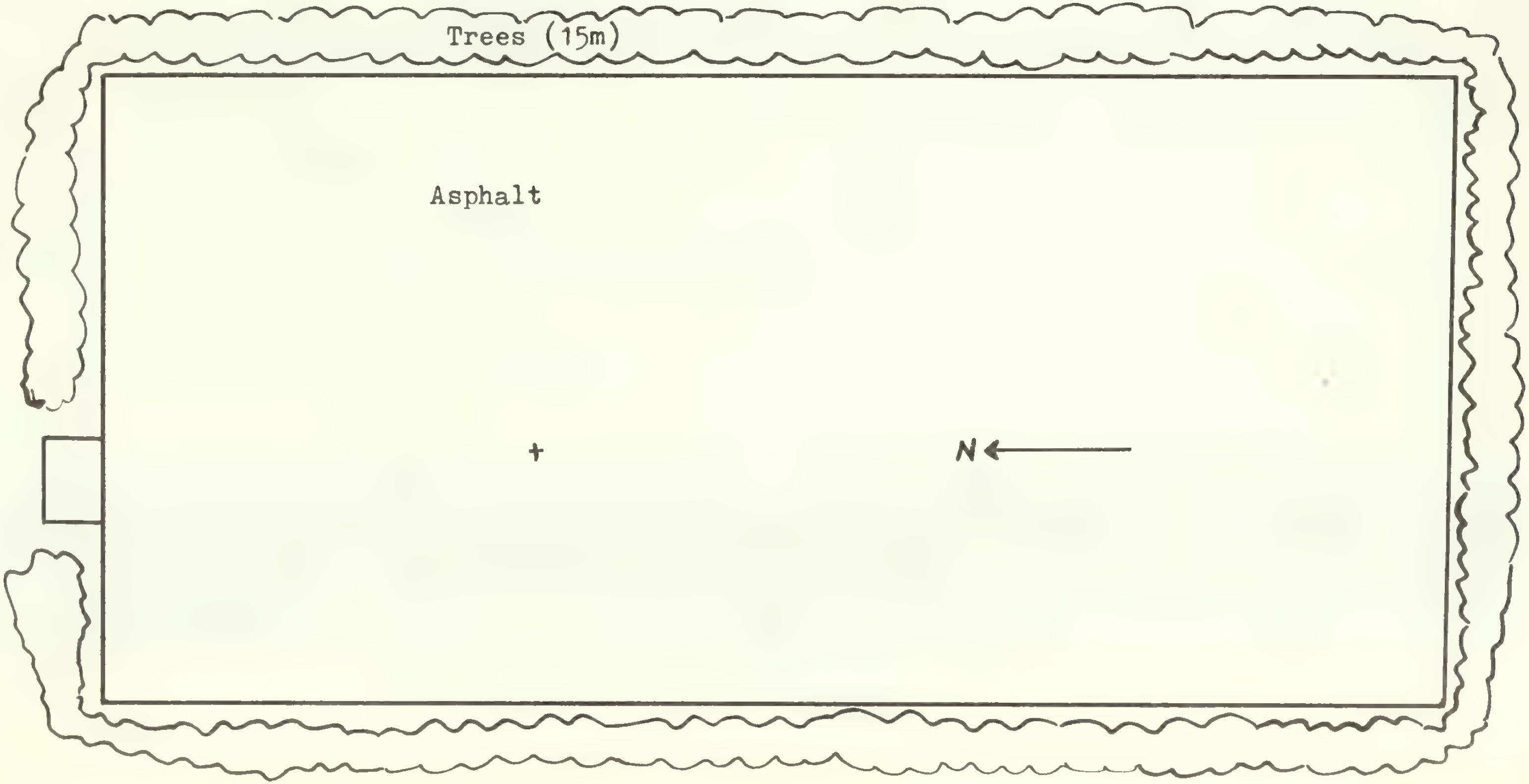
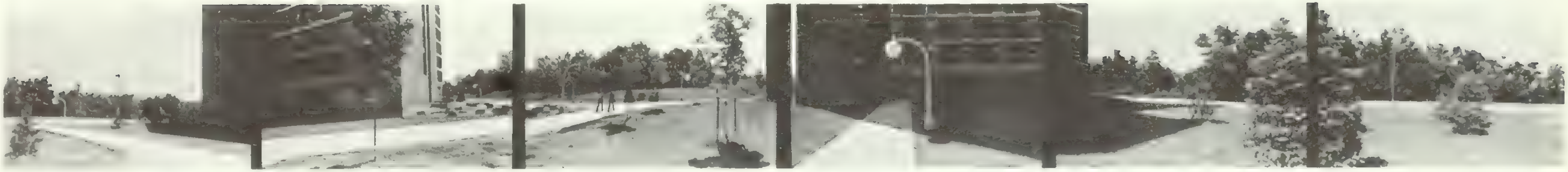
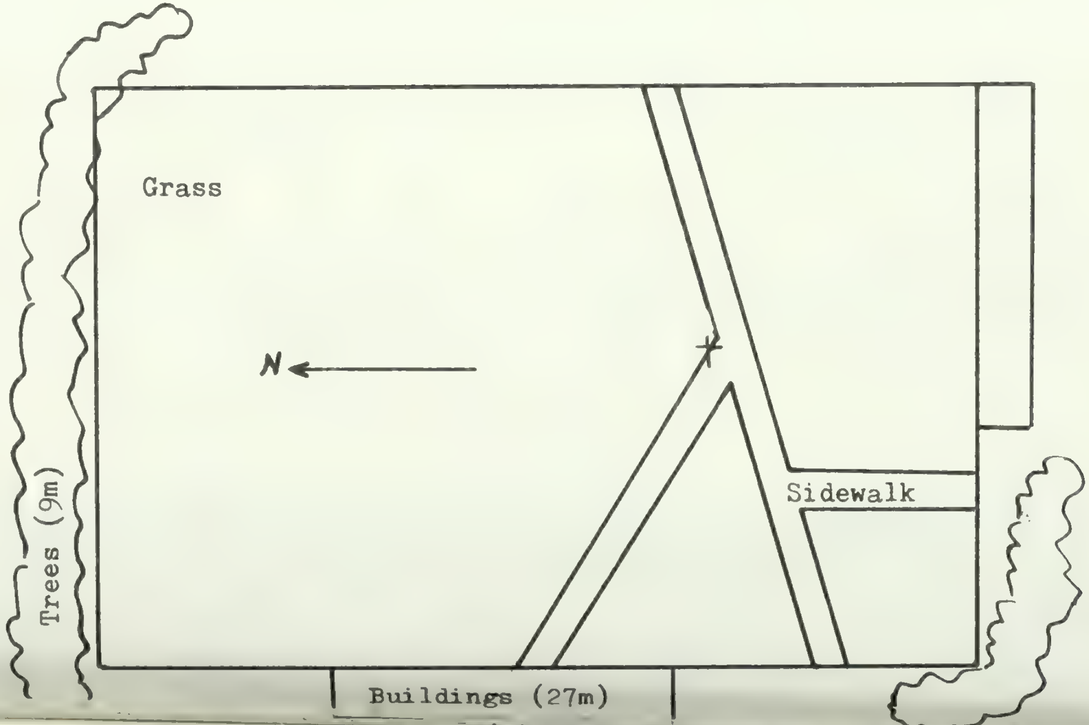

Trees (15m)
Asphalt
+
N

Figure 2.—Site number three. (+) denotes measurement site.





Site number four. (+) denotes measurement site.

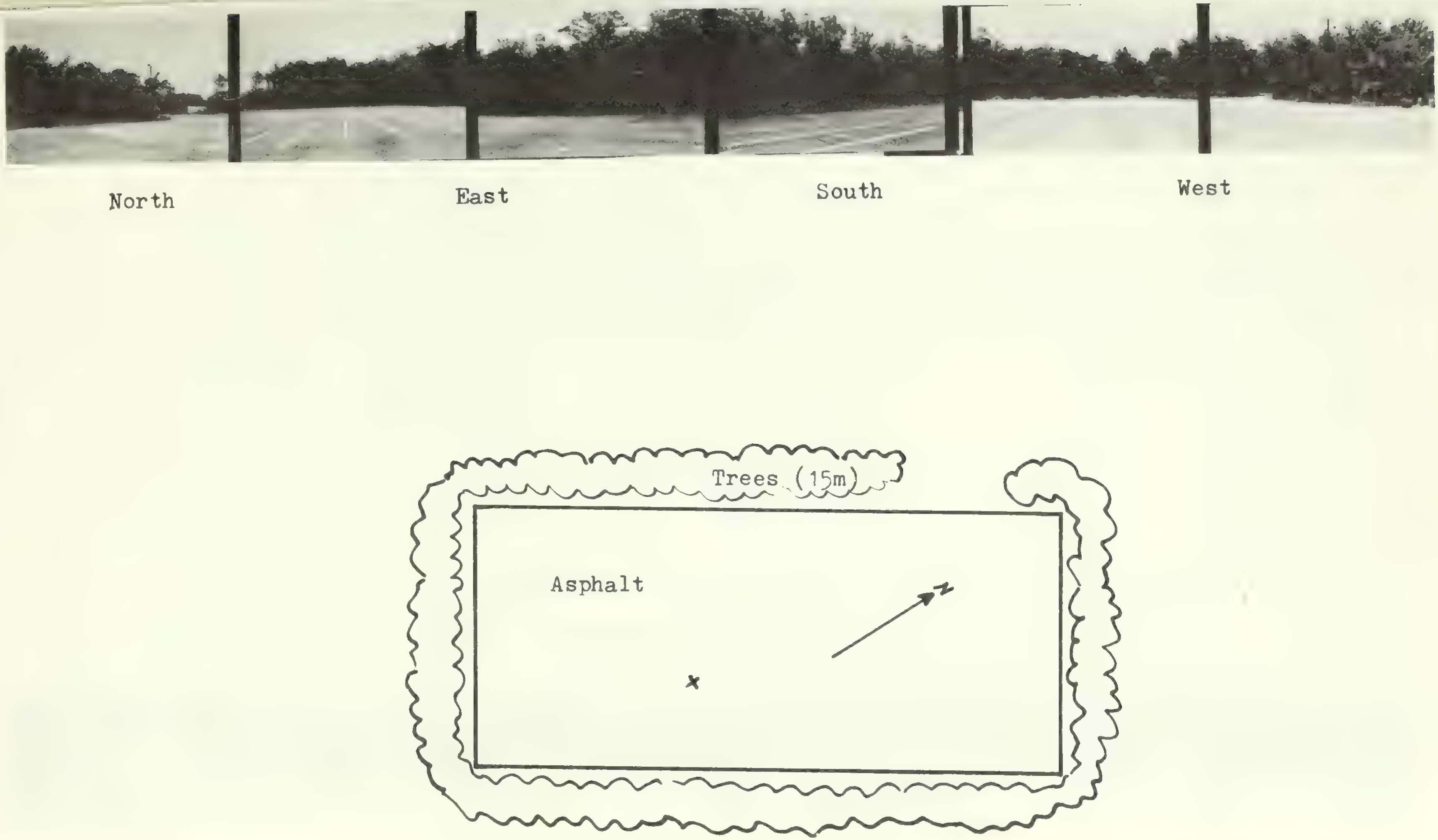


Figure 4.—Site number five. (+) denotes measurement site.

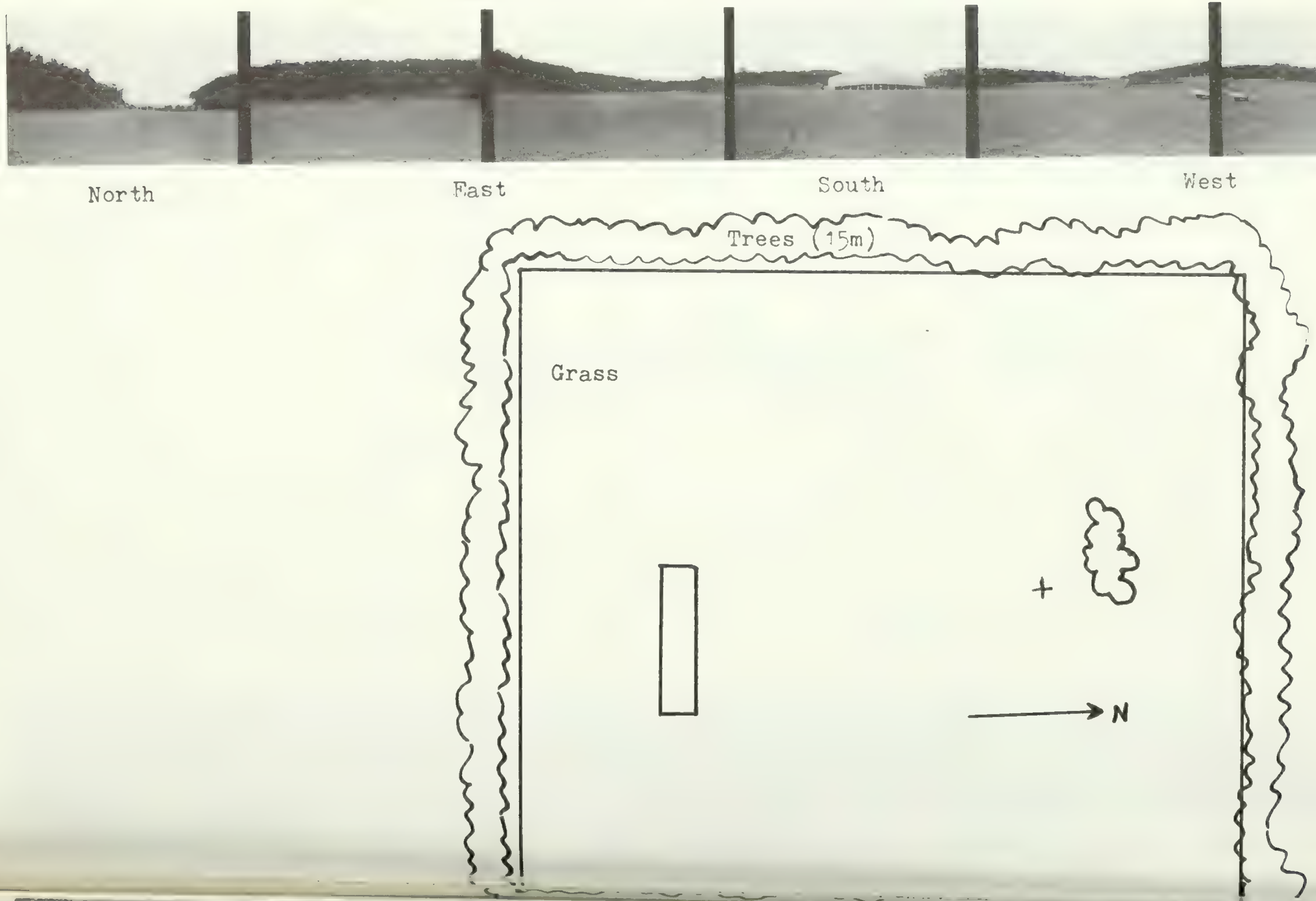


Figure [illegible].—Site number six. (+) denotes measurement site.

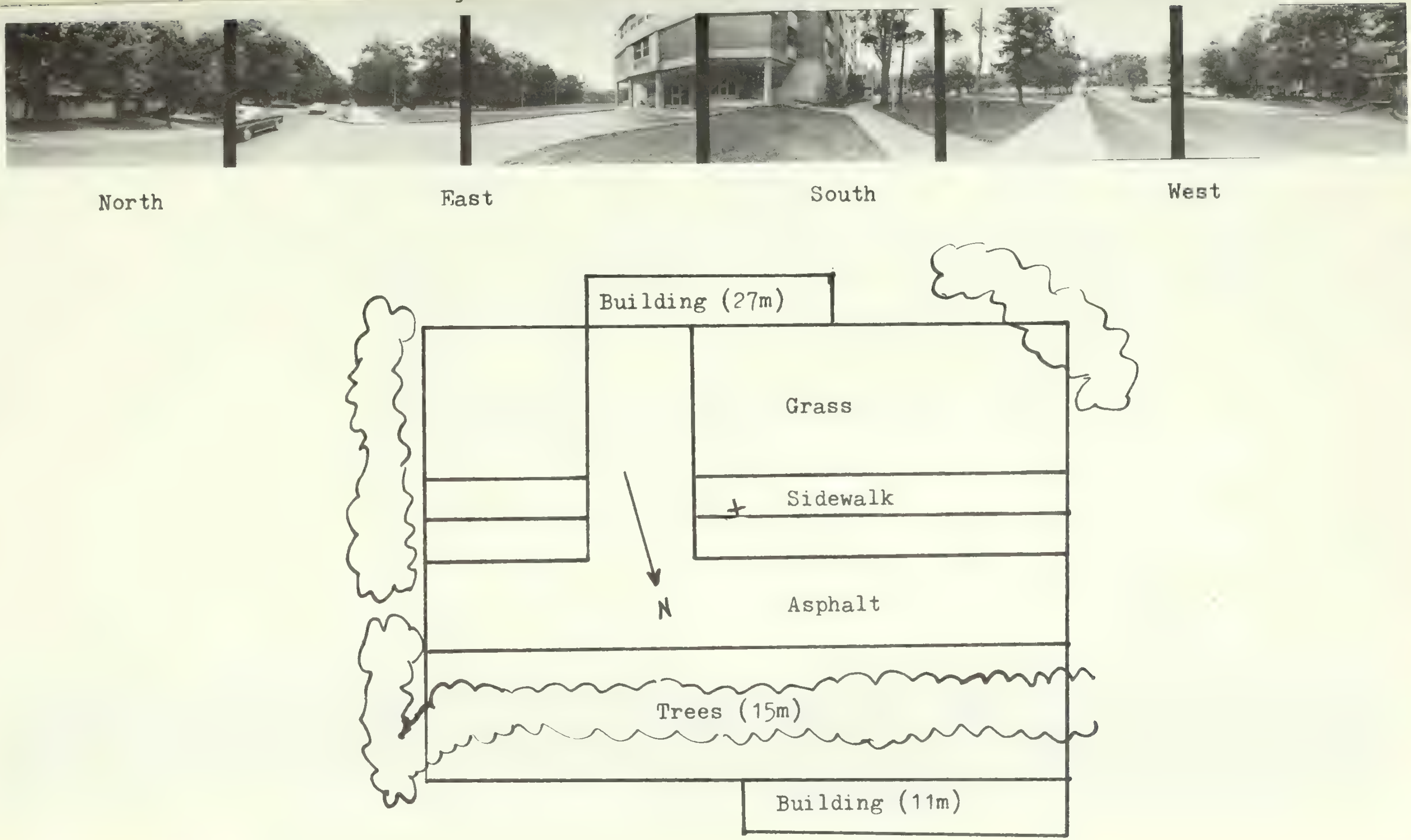
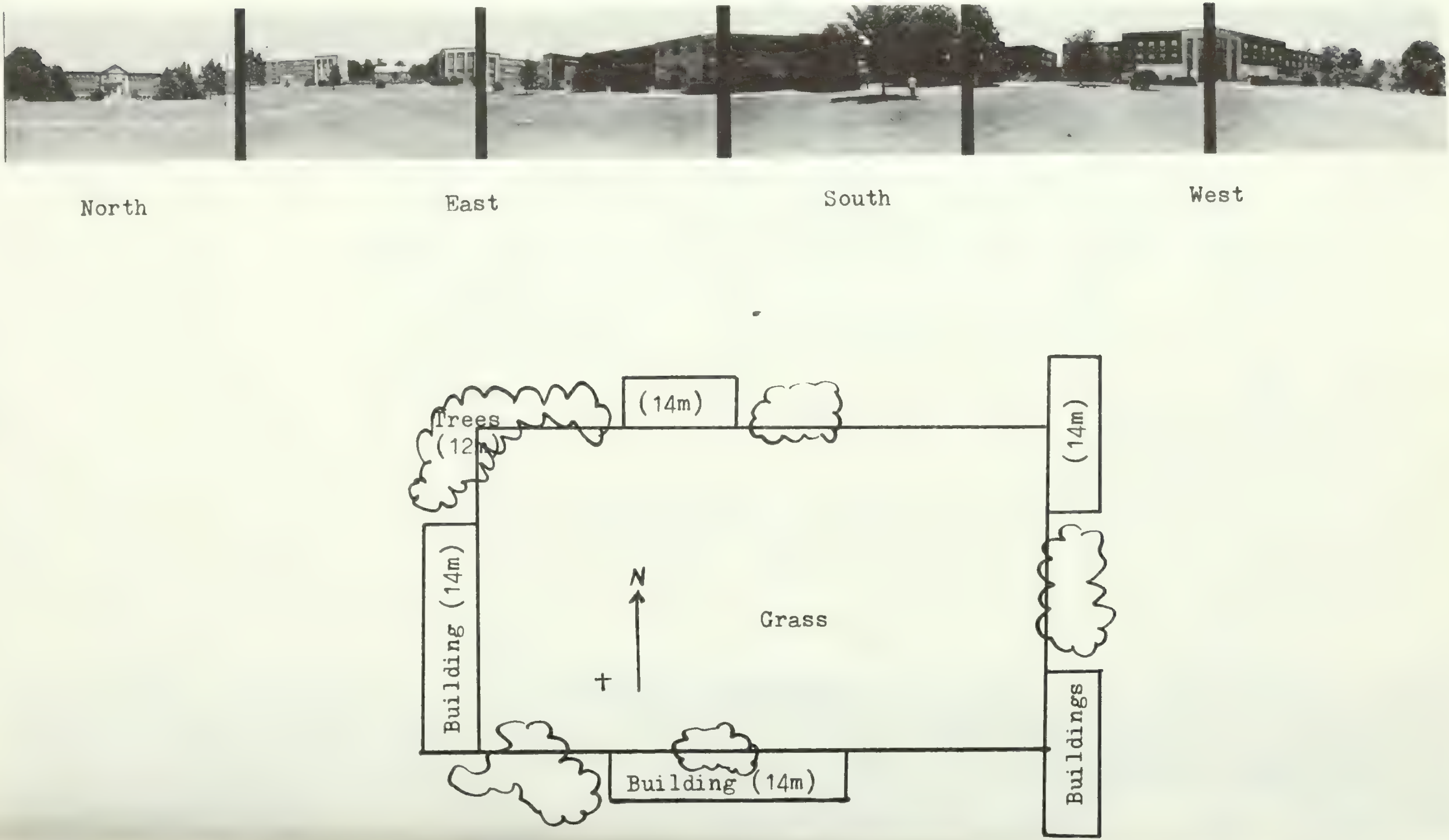
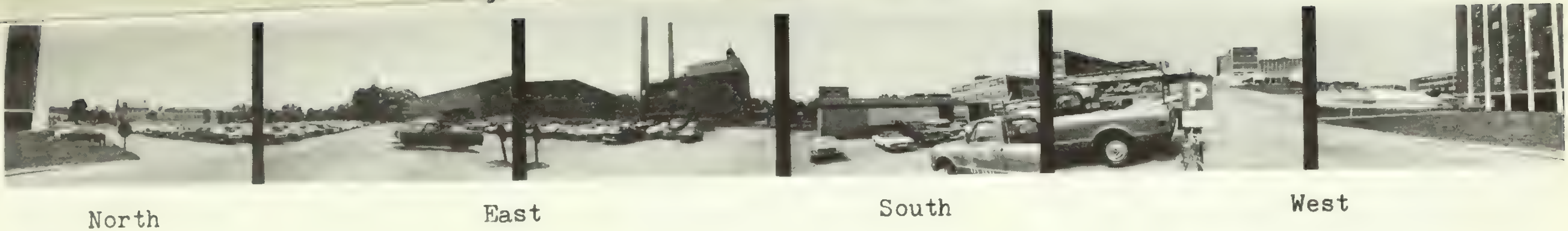
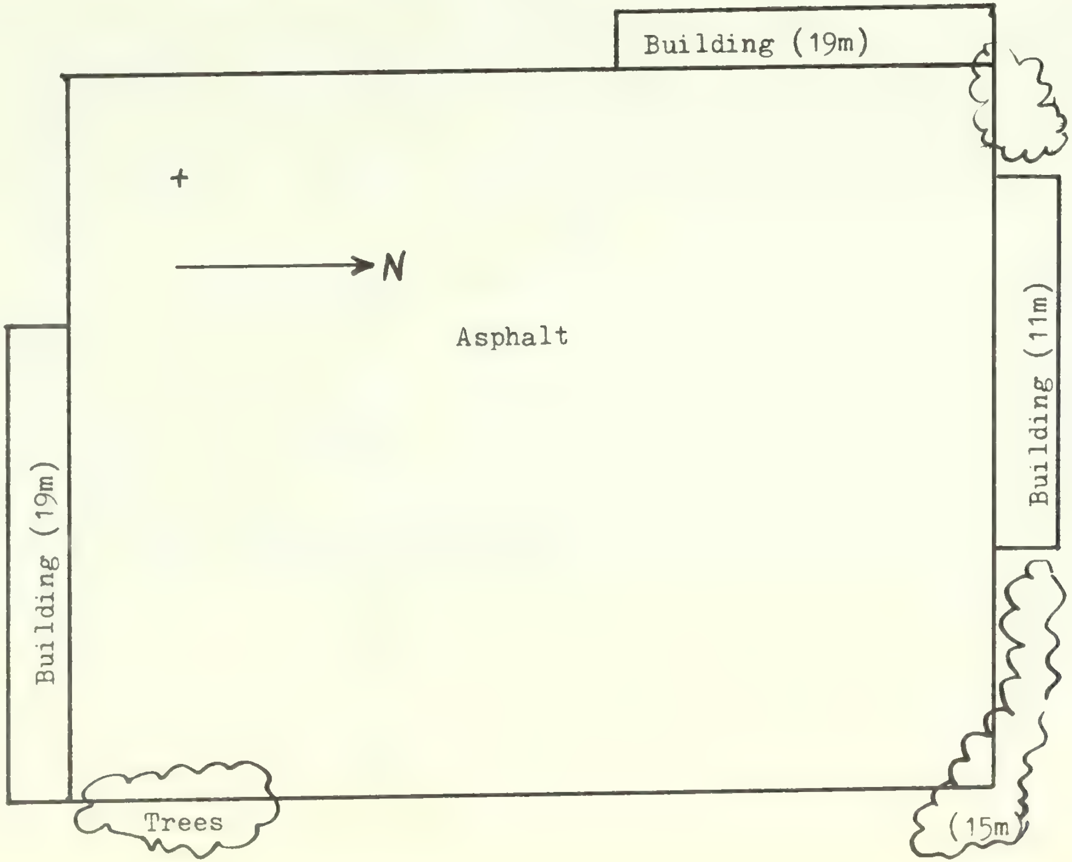


Figure 6.—Site number seven. (+) denotes measurement site.



number eight. (+) denotes measurement site.





duction (G) for a standing subject was assumed negligible. Finally, it was assumed that the subject would be in complete equilibrium with his clothing so that any heat gained or lost at the outer surface of the clothing would represent an equal heat gain or loss to the subject.

After making these assumptions and reducing all units to cal min^{-1} for the subject, we devised a working model from equation 3:

$$(\text{DRA})\ (\text{s})\ .8+\text{M}+\text{Vf}_{\text{s-o}_\text{n}}\ (\text{Ro}_\text{n}—\text{R}_\text{s})\ +\ 10.56\ (36—\text{pa})\ +\ 3.8\ (44—\text{Pa})\ +\ 2.3\ (34—\text{ta})+33.18\text{hc}\ (35—\text{ta})$$
$$=\text{net heat load before evaporation of sweat (cal. min}^{-1}) \qquad [4]$$

where:

DRA = The direct radiational area determined, using the work of Underwood and Ward *(1966)*.

$\text{Vf}_{\text{s-o}_\text{n}}$ = The view factor between the subject and the indicated object (n) in the environment, determined by using the graphic methods of Fanger *(1970)*.

R_s and Ro_n = The radiosites of the subject and objects respectively calculated by the Stefan-Boltzmann Law: $\text{R} = \epsilon\sigma \text{T}^4$, where the emissivity ($\epsilon$) was assumed unity, σ is the Stefan-Boltzmann constant, and T is surface temperature (°K).

Pa = Air vapor pressure (cm Hg).

ta = Air temperature (°C).

hc = Convective coefficient, using Fanger's *(1970)* equation: $\text{hc} = 10.4 \sqrt{\text{v}}$, where v is the wind velocity (m sec^{-1}).

M = Metabolic heat production, assumed constant at 3016 cal min^{-1}.

RESULTS AND DISCUSSION

The sites were evaluated with equation 4 and were compared in terms of relative humidity, vapor pressure, wind speed, and air temperature as well as net heat load. Figure 8 shows a graph of the net heat loads for each site averaged for all 8 test days. On this graph, points above the x-axis represent positive heat loads or conditions in which a subject must get rid of excess heat by evaporation of liquid sweat in order to be comfortable. Thus, those sites that reach the greatest positive values and are above the x-axis the longest time during the day are the most uncomfortable. Sites 2, 4, 6, and 8 were singled out in this manner.

Table 1 gives the percentage of the total view of each site represented by various groupings of materials and averaged midday air temperatures, humidities, and wind speeds. Despite the obvious physical differences among site 1 to 8, the average air temperatur vapor pressure, and wind speed varie little. A comparison of the view facto information in table 1 with the net heat load data revealed a correlation betwee midday net heat loads (0930 throug 1530) and the percentage view factor of synthetic and vegetative materials.

Regression analyses were made of th importance of the view-factor grouping of vegetation, synthetic materials, sk and not sky in determining net hea loads. Separate analyses were made f day-long averages, for transition perio (0730 and 1730), and for midda periods. Table 2 shows some results these regressions.

Table 2 shows that there was ve little correlation between net heat loa and either vegetative or synthetic vie factor groupings during the transiti periods when surface temperatures we relatively low. Further, the correlatio for individual days and times beca higher as the overall synoptic conditio became hotter. This indicates that t

Figure 8.—Average net heat loads for June and July data days.

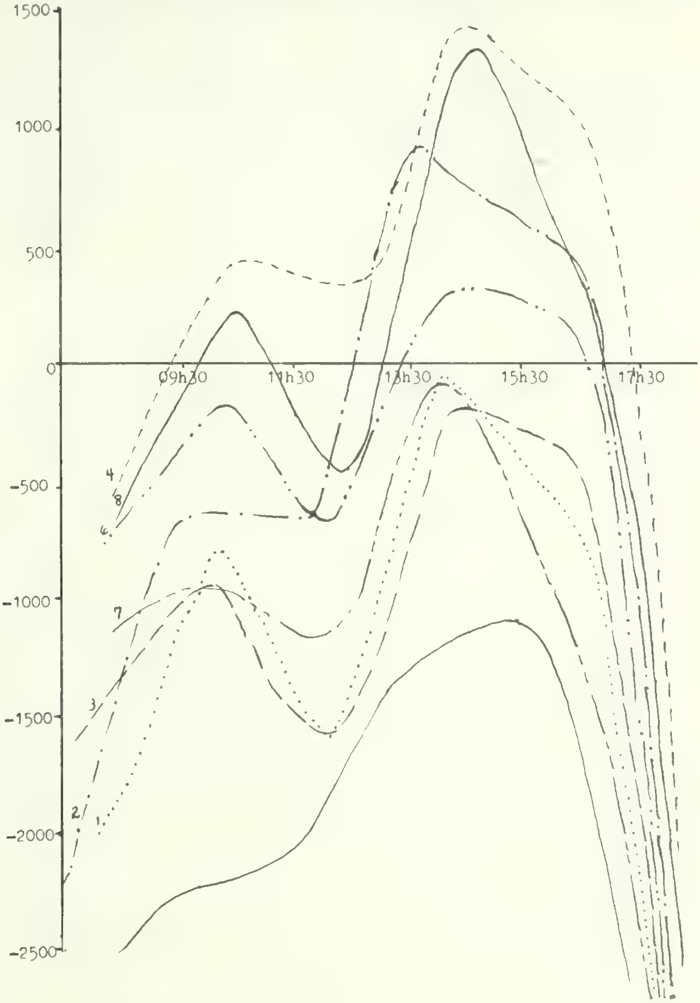


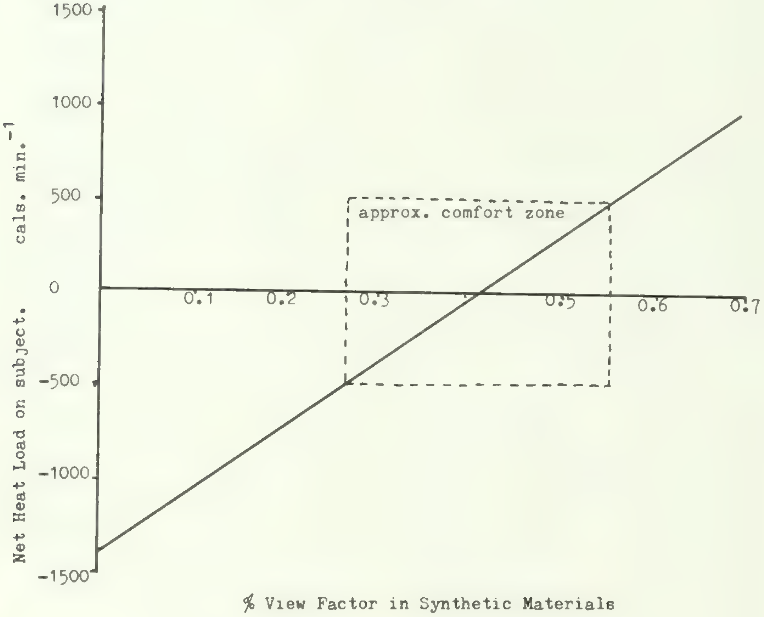
Table 1.—View-factor descriptions of sites and their average midday air temperature, vapor pressure, and wind speed

Site	Sky	Vegetation	Synthetic material	Average midday Air temperature	Average midday Vapor pressure	Average midday Wind speed
	Pct.	*Pct.*	*Pct.*	*C*	*cmHg*	*m sec*$^{-1}$
1	0	100	0	24°	12.0	0.46
2	49	3	48	26°	10.4	.91
3	24	57	19	26°	10.2	1.06
4	28	24	48	27°	10.2	.73
5	50	50	0	26°	10.5	.94
6	27	37	37	27°	10.1	.96
7	40	46	14	26°	10.3	.92
8	43	0	57	27°	10.3	.98

Table 2.—Partial results of the statistical correlations between the indicated view-factor category and averaged net heat loads

Period	View-factor category	Sites	r	$S_{y \cdot x}$ (cal. min^{-1})
Midday, June and July . . .	Synthetic materials	1-8	0.88	334
	Synthetic materials	1-4, 6-8	.93	270
	Vegetation	1-8	— .88	338
	Vegetation	1-4, 6-8	— .87	359
Transition, June and July . . .	Synthetic materials	1-8	.69	361
	Vegetation	1-8	— .46	420

Figure 9.—Average midday heat load versus the fraction of view in synthetic materials.



effect of these view-factor groupings in the urban microclimate increases as the overall climatic stress becomes more and more positive.

During the midday periods, correlations between net heat load and vegetative and synthetic categories were high. The regression analysis of the midday heat loads versus the percentage view factor in synthetic materials suggests that 87 percent of the variation in heat load from site to site can be explained by changes in the percentage view of synthetic materials.

Figure 9 shows this empirically defined relationship between the vie factor grouping of synthetic materia and midday net heat loads:

$$\text{Net heat load} = —1463 + 3574\ Vf_{syn.}$$

[

By reading the percentage of the vie factor present, at a proposed site, synthetic materials from the x-axis, estimate of the expected heat load c be read from the point of intercept wi this line. Given relationships of th nature, one should be able to design site to fall within the comfort zone manipulating vegetative shields a building spacing.

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Design of Outdoor Urban Spaces for Thermal Comfort

by HARRIET J. PLUMLEY, *research assistant, School of Landscape Architecture, State University of New York College of Environmental Science and Forestry, Syracuse, N. Y.* *This research was supported in part by funds provided by the Northeastern Forest Experiment Station through the Pinchot Institute for Environmental Forestry Research, Consortium for Environmental Studies.*

ABSTRACT.—Microclimates in outdoor urban spaces may be modified by controlling the wind and radiant environments in these spaces. Design guidelines were developed to specify how radiant environments may be selected or modified to provide conditions for thermal comfort. Fanger's human-thermal-comfort model was used to determine comfortable levels of radiant-heat exchange for various activities, clothing types, and climatic conditions. A comparison of these radiant quantities with measured and calculated quantities of radiant exchange expected for a person in urban spaces revealed several design guidelines.

EFFORTS BY PUBLIC AGENCIES and private interest groups to revitalize the central business districts in American cities have often included large expenditures for outdoor pedestrian spaces. Many such amenity spaces have failed to receive more than light use. This failure has been attributed partly to a general disregard for the physical-comfort needs of the users *(Whyte 1972)*. The need for thermal comfort is ubiquitous, but it seems often to be forgotten in the designs of outdoor spaces.

The general aim of this study was to determine how designers could modify climatic conditions in urban spaces for thermal comfort. Human thermal comfort is "that condition in which a person expresses satisfaction with the thermal environment" *(Fanger 1970)*. It is a subjective response based on both physiological and psychological states of a person in a given environment.

Climatic factors that affect heat exchange with the body are air temperature, humidity, radiation, and air movement. Other factors include the person's activity level, clothing type, and emotional and physical conditions. Previous studies *(Lewis et al. 1971, Vittum 1974)* have shown that air temperatures an relative humidities do not vary sign ficantly throughout the downtown ou door space system despite differences i physical structures and arrangement Wind speeds and radiation were mu more variable. The designer could ther fore modify microclimates in outdo spaces through control of the wind a radiant environments. This paper fo uses on the radiant heat environment

A person exchanges radiant heat wi his surroundings as does any other ph sical object. Solar radiation always ad heat to a person. The atmosphere a terrestrial objects add or remove he from a person depending on the te perature difference between the perso outer surface and the surrounding s faces. If the surroundings are warm the person gains heat. If they are cool he loses heat.

Several questions were addressed order to understand the design possib ities for altering radiant-heat exchang in outdoor spaces. How much radia heating or cooling is needed for therm comfort? When is the radiant heati or cooling needed? How much radia heat exchange is available to a pers in an urban space? A comparison of t lesirable and available radiant-heat exhange quantities revealed design guideines that could be used for selecting nd designing outdoor spaces with comfortable radiant environments.

RADIANT EXCHANGE FOR THERMAL COMFORT

A person must maintain a constant leep body temperature by balancing heat ains and losses with the environment. hermal conditions that enable a person o maintain heat balance through minor hysiological adjustments (a state of hermal neutrality) are the conditions eople subjectively select as comfortable *Bruce 1960, Fanger 1970)*.

Studies with human subjects have nown that radiant heating and cooling n comfortably compensate for cool and arm air temperatures respectively, as ng as air movement is low. The radint environment may be asymmetric bout the person as long as nearby round and vertical surfaces are within mfortable temperature ranges — round surfaces should be between 17 d 40°C; vertical surfaces should be tween 15 and 50°C *(Gagge et al. 1965, gge et al. 1967, McNall and Biddison 70)*.

termination of Comfortable nges of Radiant-Heat Exchange

Fanger's *(1970)* human thermal-comfort model was used in this study to determine radiant-exchange quantities that will yield thermal neutrality depending on other climatic conditions and a person's activity level and clothing type. Fanger's model has been tested extensively with human subjects (in indoor controlled climatic environments) to find the relationship between a person's heat balance and his subjective thermal response.

Although there is no single thermal environment that can satisfy all persons, there are ranges of conditions that are comfortable to a majority of people. Fanger tested his thermal-comfort equation to determine the percentage of people who express dissatisfaction at different thermal sensation conditions, as defined by his model. For the purpose of this study, I selected the range of thermal responses that were found to satisfy more than 50 percent of the people. This includes thermal sensations from slightly cool to slightly warm. The ranges of comfortable radiant-exchange quantities calculated from Fanger's model should be applicable to all healthy persons regardless of age, sex, geographic location, or body size, as long as differences in clothing habits are recognized *(Fanger 1970, Rohles and Johnson 1972)*.

QUANTITIES OF RADIANT EXCHANGE IN OUTDOOR URBAN SPACES

Three sources of radiant heat exchange, exclusive of artificial radiant heat, are available to persons in outdoor environments:

1. Solar radiation: the direct beam, the diffuse radiation from the atmosphere, and reflected radiation from the ground and the vertical surfaces.
2. Longwave radiant exchange with the sky.
3. Longwave radiant exchange with terrestrial surfaces (ground, vertical, and overhead surfaces).

Determination of Radiant-Exchange Quantities

Many environmental factors and a person's physical factors affect the amounts of radiant heat exchanged with a person from these three sources. For this reason, radiant quantities were determined for some specific conditions for persons located in a city in the northeastern United States. Syracuse, N.Y., was chosen for convenience. Conditions were chosen for times when people are most apt to be using outdoor spaces and for typical urban street configurations and surface materials.

A sample of quantitative estimates of a person's net radiant exchange with each of the three sources was calculated. Solar radiant quantities were calculated by using the equations in Terjung and Louie *(1971)*. Fanger's *(1970)* information on the radiant geometry of a person was used to determine solar radiant quantities absorbed by a person. Solar radiation on cloudy days was computed from Ångstrom's equation as given in Gates *(1962)*. Calculations of net radiant exchanges with the sky and terrestrial surfaces were made with a modified radiation law as described in Plumley *(1975)*. Sky temperatures were derived from Brunt's table of atmospheric radiation in Brown *(1973)*. Terrestrial surface temperatures of typical urban materials were measured in Syracuse during different climatic conditions. The information on a person's radiant area in view of surrounding flat surfaces was taken from Fanger *(1970)*.

Tables of radiant exchanges for the following conditions are presented in Plumley *(1975)*:

1. Solar radiation absorbed by a person on clear days for four different body postures.
2. Total solar radiation absorbed by a person on clear days in the shade of a building, a thin-canopy tree, and a dense-canopy tree.
3. Solar radiation reflected by a glass wall and absorbed by a person.
4. Total solar radiation absorbed by a person on totally overcast days (altostratus and stratus clouds).
5. Net longwave radiant exchange under clear and cloudy skies during different air temperatures (for a person in three typical urban street configurations).
6. Net longwave radiant exchange with typical urban ground and vertical surface materials, shaded and unshaded, at four different times of the day for four air temperature conditions (cool, moderately warm, warm, and hot) typical of the spring, summer, and fall seasons in the northeastern United States.

Summary of Analysis of Radiant Exchange Quantities

Net radiant exchanges of less than 20 to 30 kcal/hr/person were considered to be insignificant because this small amount does not produce a change in a person's thermal-sensation level, as based on an analysis of Fanger's model *(Plumley 1975)*. Therefore, physical factors in the environment that showed insignificant differences in the radiant-exchange quantities for a person were considered to be unimportant for the design of urban spaces.

Some of the results of an analysis of the radiant quantities are presented here, as taken from Plumley *(1975)*:

Solar radiation

1. Direct solar radiation provides much more radiant heat to a person than any of the terrestrial surfaces. Even on cloudy days at noon, diffuse solar radiation can provide 5 to 10 times more radiant heat than terrestria surfaces.
2. Differences in ground-surface reflectivities (in the range of 20 to 40 percent) are not important during morning or late afternoon. During th midday, higher-albedo materials significantly increase the amount o solar radiation incident on a person The albedo of shaded ground surface is unimportant.
3. Solar radiation reflected from typical large tinted-glass office window does not provide significan amounts of heat to people.
4. To maximize the solar radiatio available to a sitting person (for co days) seats should be positioned face the sun, and the ground materi should be moderately reflective (li light brick or concrete).
5. To minimize the solar radiation person receives (on warm day shade from trees with dense canopi should be provided. Trees with th canopies, like honeylocusts *(Gledits*

Figure 1.—Solar radiation absorbed by a person in the open and in the shade of trees with dense and thin canopies.

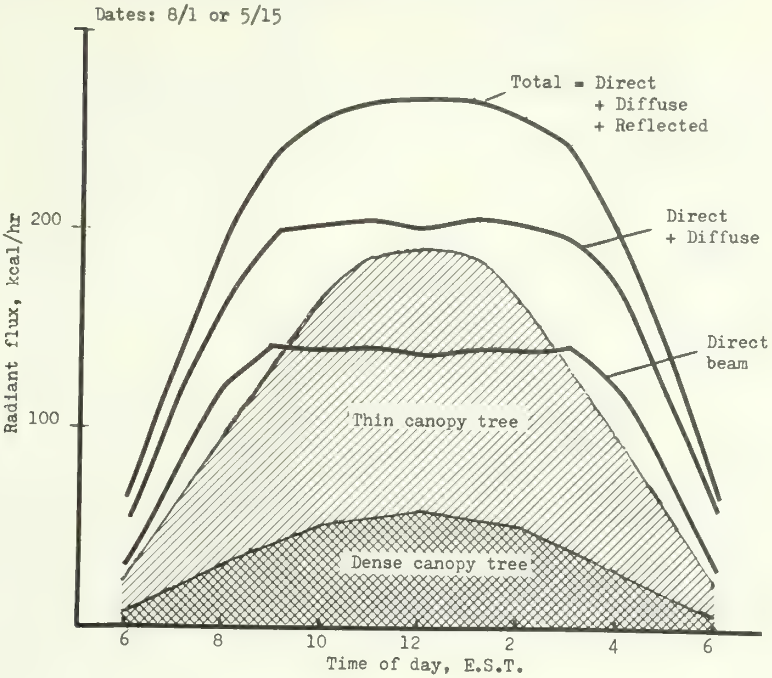


Table 1.—Effect of radiant exchange for a person on an urban street under clear and cloudy skies

Condition	Activity			Effect
	Sitting	Walking slowly	Walking quickly	
Clear skies	< 85°F.	< 75°F.	< 60°F.	Cooling
	upper 80s to 99°F.	upper 70s to 99°F.	upper 60s to 90°F.	Neutral
	—	—	> 95°F.	Heating
Cloudy skies	< 65°F.	< 55°F.	—	Cooling
	upper 60s to 95°F.	upper 50s to 85°F.	40° to 75°F.	Neutral
	> 95°F.	> 85°F.	> 75°F.	Heating

Note: The air temperatures considered here are for the range from 30 to 99°F. The clothing types used for this table were those typically worn during the different air temperatures.

triacanthos), are not as effective for shading as dense-canopy trees (fig 1).

diant Heat Exchange with the Sky

The sky can be a source of radiant cooling or heating depending on the air temperature and cloudiness. During warm weather the clear sky can have a cooling effect only for seated persons or slow walkers (table 1).

2. In cool weather radiant cooling is undesirable, and spaces should provide overhead obstructions to those portions of the sky not in the direction of the sun.
3. In warm weather radiant cooling is

desirable. Spaces for sitting should not be located directly under overhead canopies and should preferably be located away from building walls in order to maximize the sky view.

Radiant Heat Exchange with Terrestrial Surfaces

1. Ground and vertical surfaces can be sources of radiant heating or cooling depending on their surface temperatures, surface dimensions, proximity to the person, and the person's activity level. Graphs were constructed to show a person's radiant exchanges with ground and vertical surfaces, each of dimensions large enough to provide the near maximum exchange (figs. 2 and 3). Surface dimensions larger than these do not significantly increase the radiant exchange for a person. This was determined from an analysis of Fanger's *(1970)* view factors between a person and ground and vertical surfaces.
2. Ground surfaces generally provide more radiant exchange than either vertical surfaces (walls) or overhead surfaces (trees or awnings). The latter usually provide negligible quantities of net radiant exchange.
3. The surface areas of ground or vertical surfaces need not be very large to provide significant amounts of radiant exchange. On warm days unshaded ground surfaces as small as 4 square meters or vertical surfaces 14 meters long and 4 meters high can provide undesirable amounts of radiant heat to a person.
4. Radiant exchange with vertical surfaces becomes insignificant for persons located more than 3 meters from the surface. (This applies to walls, 10 meters high and 14 meters long, with surface temperatures between 10 and 40°C—typical of the extremes found in the summer and fall seasons in Syracuse.
5. During warm weather, shaded ground surfaces offer significantly less radiant heat to persons than unshaded surfaces, with the exception of vegetative ground materials (fig. 4).
6. Walls shaded by dense-foliage trees offer significantly less radiant heat to persons than unshaded walls. Walls shaded by vines or shrubs did not show significantly lower surface temperatures than the unshaded portions, and differences in net radiant exchange with persons were negligible.

DESIGN GUIDELINES

Comparisons of available radiant exchanges were made for: (1) conditions providing the maximum amount of radiant heat gain, and (2) conditions providing the least amount of radiant heat gain (or most radiant heat loss) from each of the three radiant-exchange sources. An example of these comparisons is presented for a seated person a noontime on a warm day (fig. 5).

Comparisons of radiant heat exchang for thermal comfort and radiant exchange available to persons reveale some simple design guidelines (figs. and 7). Four elements, as indicated o the charts, should be considered in th design of a space depending on the ai temperature conditions, time of day, an the person's activities:

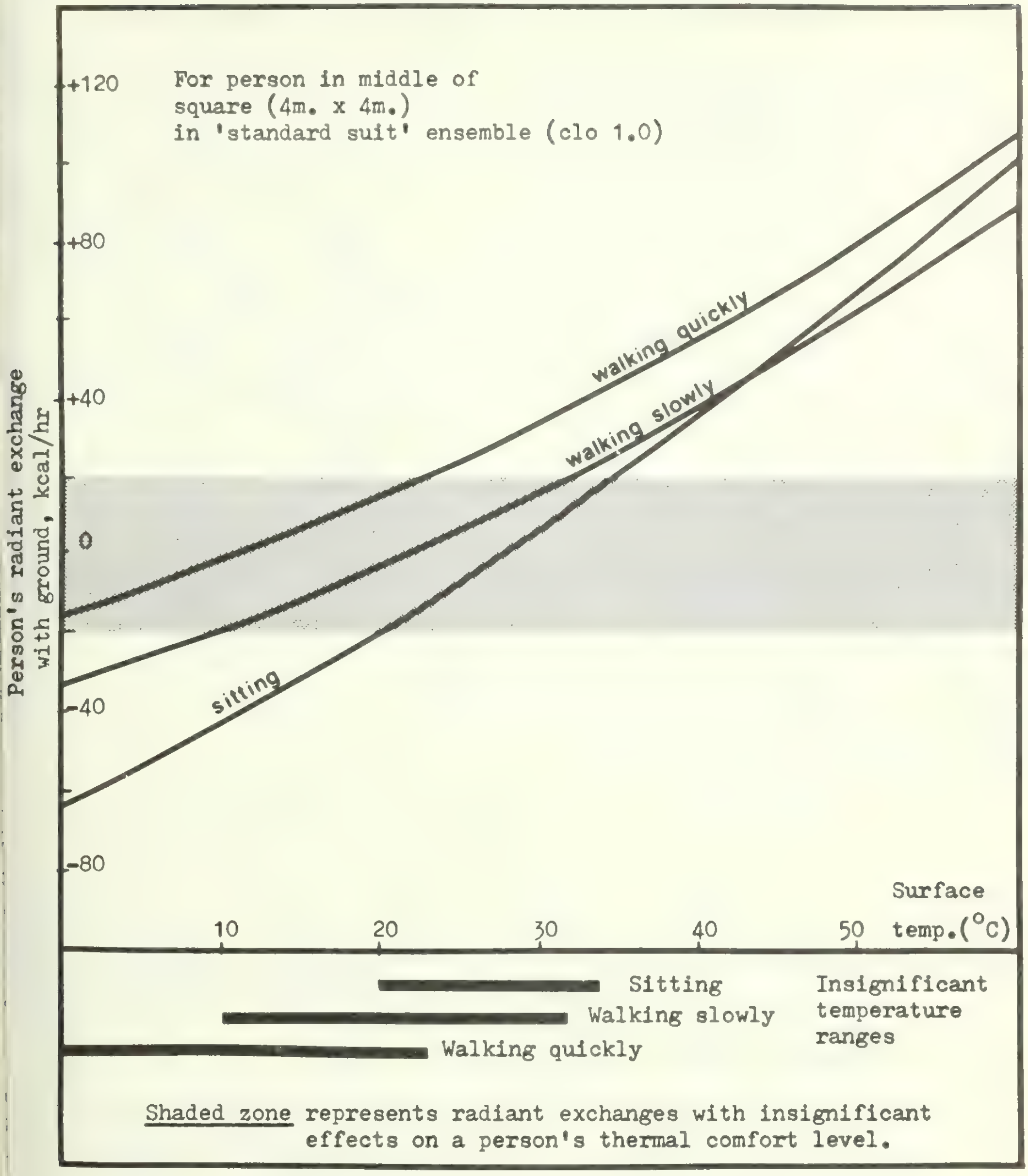
1. Direct solar radiation should eithe be available or should be shaded b thin or dense-canopy trees.
2. Ground and vertical terrestrial surfaces should be shaded or unshaded
3. Sky views overhead and to the side of persons should be either blocke or made as large as possible.
4. Wind speeds should be either calm low (1 to 3 mph), or moderate (4 t 5 mph).

Footnotes accompanying the chart provide additional specifications fo some of the categories.

Artificial Radiant Sources

Spaces can be designed to includ artificially-warmed ground and vertica

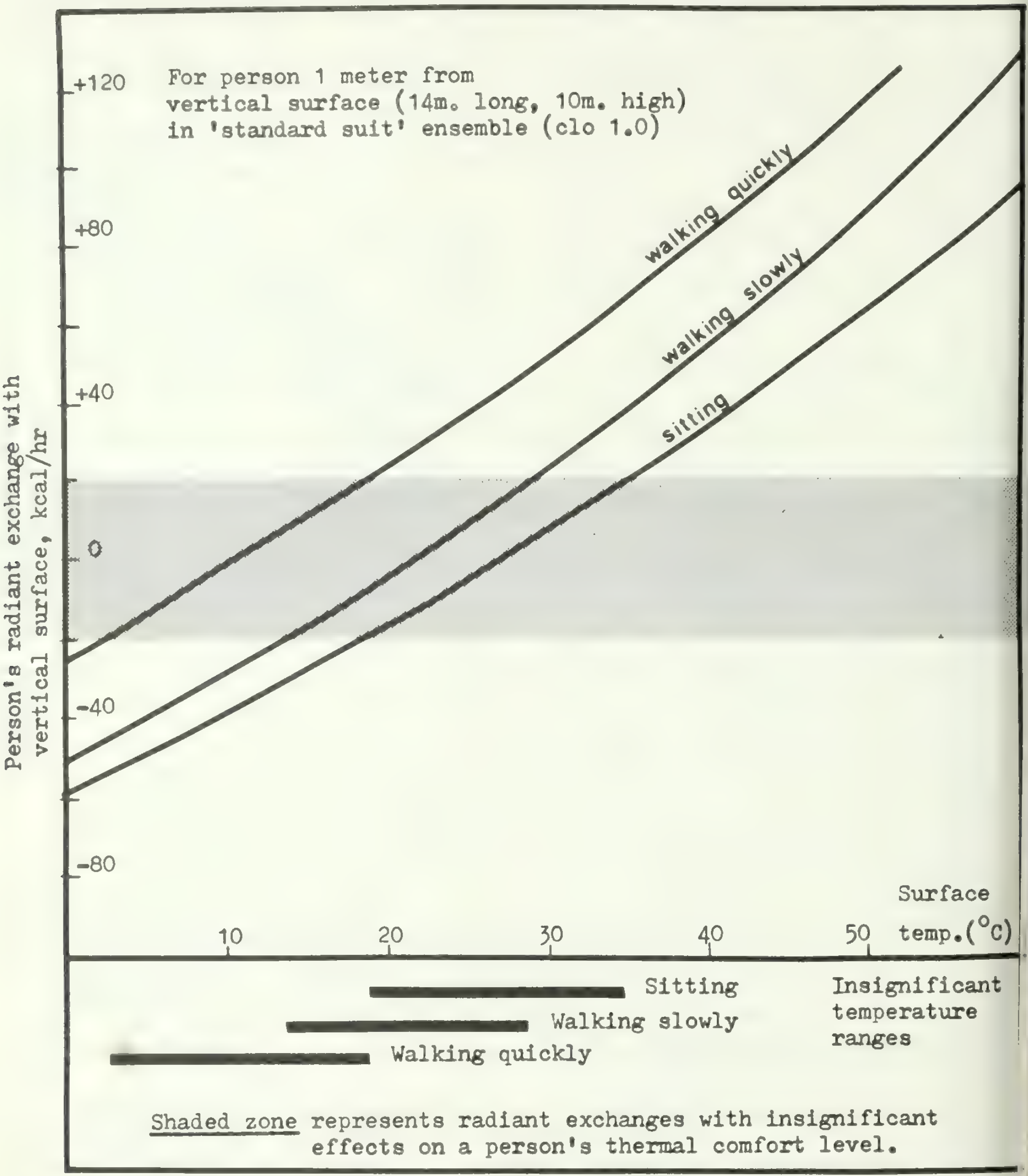
Figure 2.—Effect of ground-surface temperature on radiant exchange between a person and the ground.



Shaded zone represents radiant exchanges with insignificant effects on a person's thermal comfort level.

Note: If clo 0.5, subtract 15 kcal/hr from radiant flux.
If clo 1.5, add 15 kcal/hr to radiant flux.

Figure 3.—Effect of surface temperature of a vertical surface on radiant exchange between a person and the vertical surface.



For person 1 meter from vertical surface (14m. long, 10m. high) in 'standard suit' ensemble (clo 1.0)

Shaded zone represents radiant exchanges with insignificant effects on a person's thermal comfort level.

Note: If clo 0.5, subtract 20 kcal/hr from radiant flux.
If clo 1.5, add 20 kcal/hr to radiant flux.

Figure 4.—Person's radiant exchange with shaded and unshaded ground surfaces on a clear warm day.

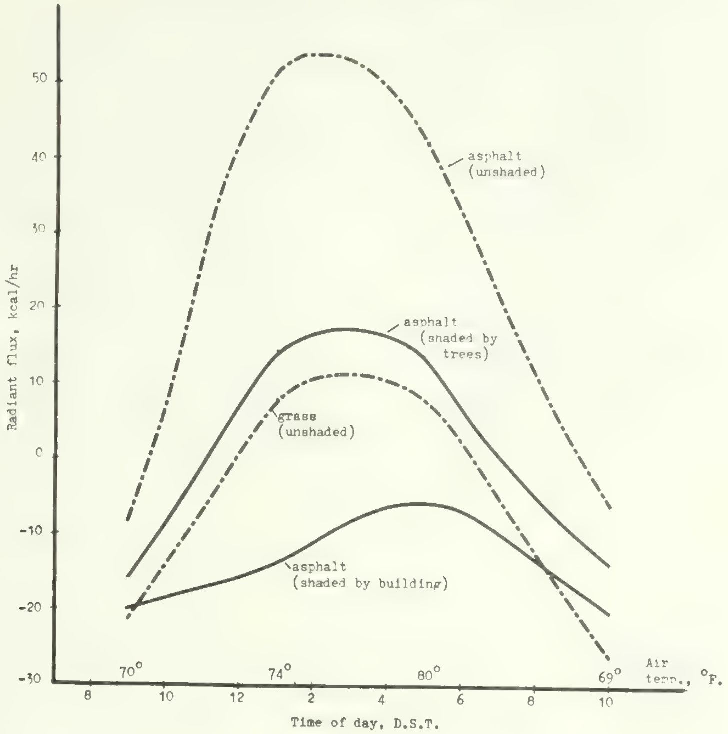
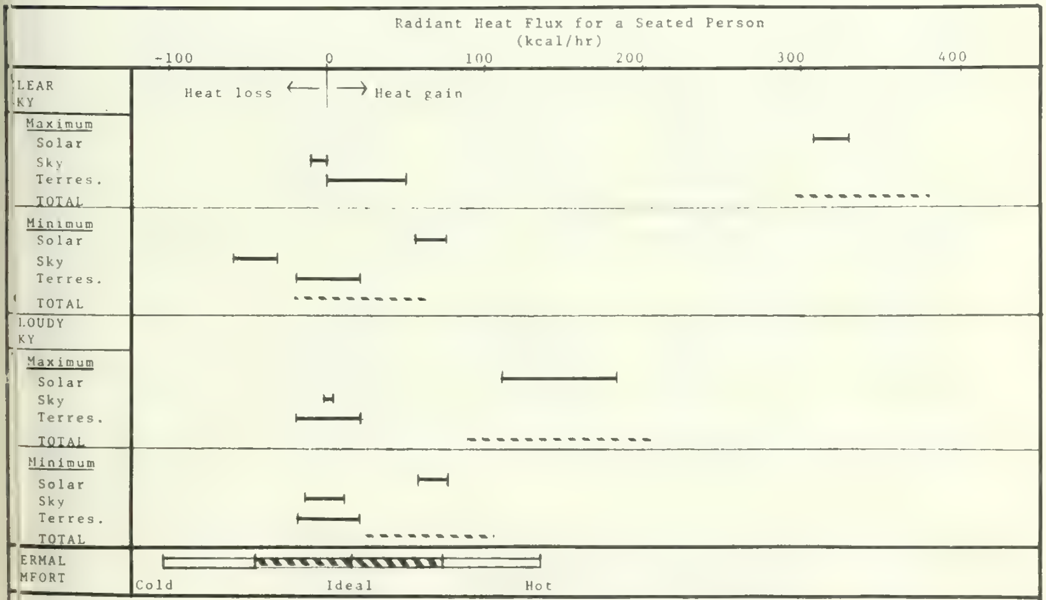


Figure 5.—Comparison of desirable and available radiant exchanges.

WARM DAY - NOONTIME



Climatic conditions: Air temp. 25°C. (77°F.), relative humidity 60%, low wind speed(1mph)
Clothing: Lightweight ensemble (clo 0.5)

Design Notes: Spaces should be designed to minimize radiant heat gain to persons for either clear or cloudy days.

Figure 6.—Design guideline chart for clear cool days.

Where the design elements are not sufficient to provide thermal comfort, the relative degree of discomfort is indicated below the activity/time of day category.

1. If ground and vertical surfaces can be artificially warmed to 40 and 50°C, respectively, a person seated near a wall in a space with a small sky view can receive enough radiant heat to feel only slightly cool.
2. If a person has a large sky view, solar radiation should be maximized (seats facing the sun and ground materials that are moderately reflective to the sun).
3. Solar radiation available to the person should be maximized. Vertical surfaces should not be near the person unless they are heated.
4. The best place on a street for a person to walk would be away from vertical walls, but on the side of the street. A row of trees between the person and the buildings can reduce the sky view.
5. If the sky view is small, a person should be over a low reflective ground material.
6. Hard, dense materials (not vegetation or wood) should be used for the ground surface. Heated ground and vertical surfaces could provide enough radiant heat for thermal comfort.
7. Ground surfaces may be shaded or unshaded. Walls facing the sun should be shaded. A person will not be cooled by wind unless he has been perspiring.

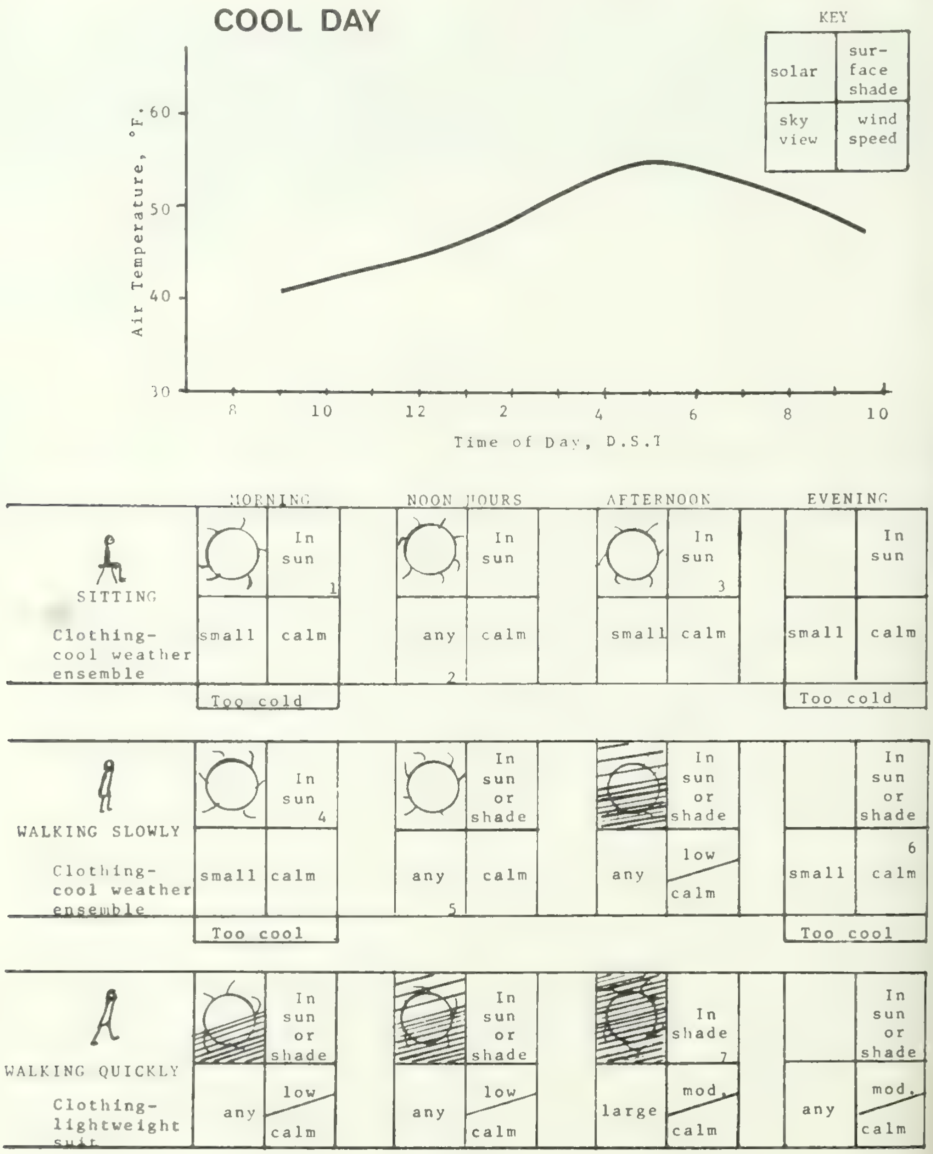
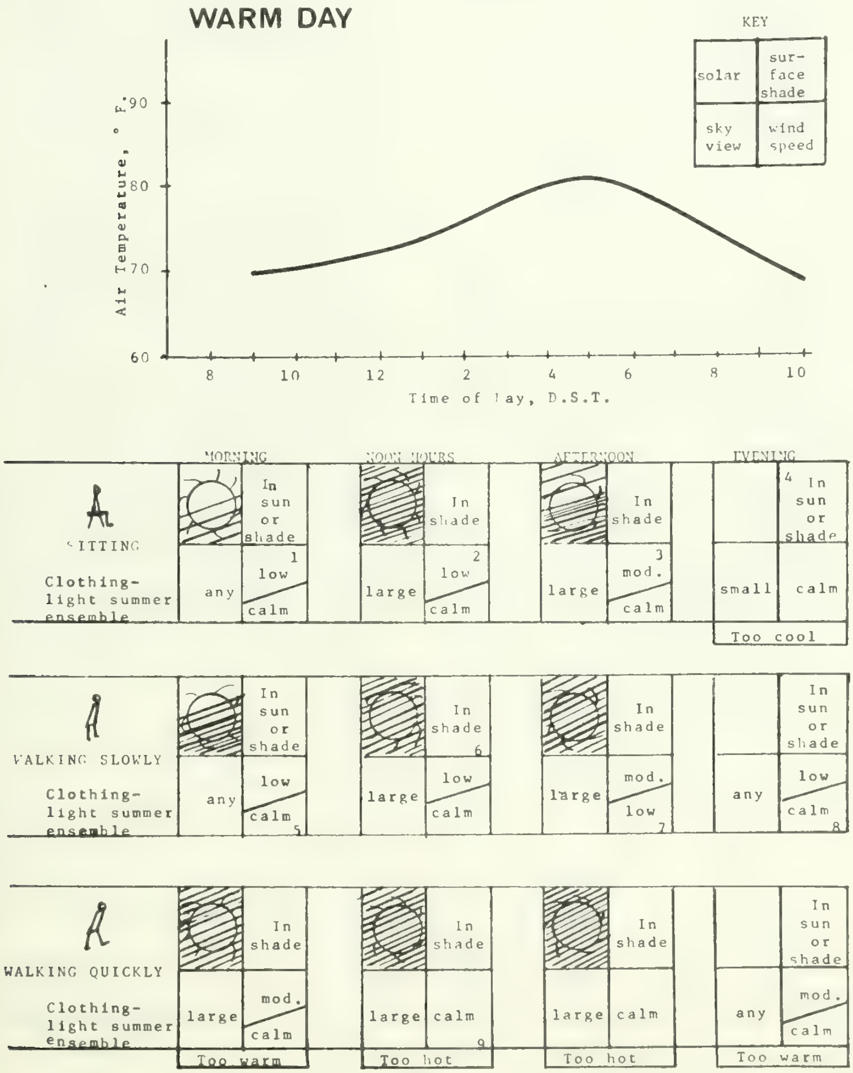


Figure 7.—Design guideline chart for clear warm days.

Where the design elements are not sufficient to provide thermal comfort, the relative degree of discomfort is indicated below the activity/time of day category.

1. If direct sun is desired, a breeze is necessary and a reduced sky view is desirable.
2. Unshaded vegetative ground surfaces and unshaded vertical surfaces are acceptable. If direct sun is desired, artificially cooled ground and vertical surfaces (for example, a water wall) with surface temperatures of at most 17 and 15°C, respectively, can provide enough radiant cooling for a person to feel only slightly warm.
3. Unshaded vegetative ground surfaces are acceptable. Light shade from solar radiation can be comfortable if the space is breezy and the person is in light summer clothing.
4. Artificially warmed ground and vertical surfaces can provide enough radiant heat to compensate for the cool air temperatures even under slightly breezy conditions.
5. If direct sun is desired, a breeze and a larger sky view are necessary. Dense tree shade is comfortable unless the space is windy and a person is dressed in light summer clothing.
6. Unshaded vegetative surfaces can be used. Persons in medium weight suit ensembles may be too warm despite these microclimatic considerations.
7. A person in medium-weight suit ensemble will be too warm.
8. If the space is breezy, it is important to minimize the sky view for a person in light summer clothing.
9. Air movement across a person will add heat to him unless he is wet with perspiration.



surfaces (for example, cooled water walls) for warm weather. Seated persons can be comfortable during noon hours at 0°C in spaces that provide the cool weather needs (fig. 6) plus ground and vertical surfaces of 40 and 50°C respectively. Spaces designed for warm-weather needs (fig. 7) can be fairly comfortable for seated persons at 31°C if cooled ground and vertical surfaces of 17 and 15°C respectively can be included.

Limitations of the Design Guidelines

These design guidelines should be applicable to cities with latitudes and climatic conditions similar to Syracuse. They are based on the thermal-comfort needs of the average healthy person who has equilibrated to the outside thermal environment. They do not take into account the special thermal desires of particular groups of people; for example, office workers coming from cool air-conditioned buildings seeking sunshine for warmth, or a tan or perspiring construction workers in need of a cool breezy space.

Outdoor spaces offering a variety of radiant environments may best satisfy a majority of the people. However, the radiant environments indicated in the design guidelines should be among the available options.

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Topoclimatic Aspects of Developmental Suitability in the Metropolitan Landscape

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ABSTRACT. — A computer-based procedure for geographically identifying rating, and ranking topoclimatic characteristics is described. The influences of topography, land use, and soils are considered and combined into a single composite topoclimate developmental suitability map drawn by a Cal Comp plotter. By allocating development to the most suitable topoclimate areas, the long-term energy costs of maintaining human health and comfort could be minimized.

THE GROWTH OF METROPOLITAN REGIONS in North America ıas not profited from the potential topolimatic benefits offered by the natural andscape. With the increasing concern or conservation of our energy reources, the long-term costs of ignoring he potential benefits of locating deelopments, in the most suitable topolimates becomes inexcusable. Basic rinciples of applied climatology should e integrated into the physical, social, nd economic principles of landscape lanning to increase human health and omfort at least cost.

At the University of Massachusetts n interdisciplinary planning research roup, operating under the acronym ETLAND (Metropolitan Landscape lanning Model), has been working on system of integrated, computer-based ndscape-assessment procedures *(Fabos 973)*.

The METLAND model is composed three major assessment procedures, efined as components. The first component identifies and evaluates special-value resources such as prime agricultural lands. The second component identifies and evaluates hazards such as high noise-pollution areas. Together, the special-value resource and hazard components identify and evaluate environmental constraints to development. The third component is the developmental-suitability component, which strives to identify and evaluate those landscape parcels possessing positive intrinsic attributes that offer maximum benefits and least cost to the resident, community, and developer.

Within the developmental-suitability component there are three variables which are assessed. These are physical (slope, depth to bedrock, etc.) visual (land-use compatibility) and topoclimatic. By assessing the physical, visual, and topoclimatic attributes of the landscape, the most intrinsically suitable areas for development may be identified, rated, and ranked. The purpose of this paper is to report on the initial procedure and results of the topoclimate developmental suitability variable of the METLAND model.

The goal of the topoclimatic assessment research was to design and implement a procedure, using established principles of applied climatology, to assess the topoclimatic suitability within a town or region for various development and planning purposes. A review of current literature was made to clarify and define the characteristics of optimum topoclimatic areas that would be most suitable for development. It was found that the most suitable topoclimatic areas would support metropolitan growth that minimizes long-term costs of maintenance over the short-term costs of development. Specifically, we should aim for long-range stability through low energy maintenance demands for artificial heating and cooling of the built environment *(Knowles 1974)*.

In addition to energy savings, we should also strive for maximizing human comfort, safety and health by taking full advantage of natural topoclimatic opportunities and minimizing regional or mesoclimatic stresses *(Mather 1974)*.

In the terminology of Olgyay *(1963)*, the most important topoclimatic objective for the New England region is to minimize underheated areas. By locating development to maximize exposure to winter solar receipts and to minimize the effects of winter winds, underheated areas can be avoided. Areas susceptible to overheating should also be avoided, although these are less significant in the New England region.

A final objective to be considered concerns fog, frost, and excessive moisture. Frequent fogs and high humidity enhance the danger of moisture damage to building materials and paint. Critchfield *(1966)* reports that, where air pollution is common, the chemical effects of moisture damage is much greater when associated with dirty fog particles.

Our task required the translation of these objectives into landscape subvariables which could be measured and used to interpret probable topoclimatic conditions within a region.

METHODOLOGY

Selection of Subvariables

Recorded climatic data for assessing towns of 10 to 40 square miles or regions of hundreds of square miles are scarce because the number of recording stations is limited. Consequently, variations in local topoclimate must be derived indirectly. Interpreting topoclimate from variations in topography (slope, orientation, elevation) has received considerable attention. The early works of Geiger *(1965)* and Olgyay *(1963)* provide much of the basis for interpreting local climatic conditions resulting from variations in topography

Another important influence on topoclimate is land use, reflecting various heat-capacity and heat-conductivity capabilities. Nicholas *(1971)*, Landsberg *(1969)*, and Mitchell *(1962)* have reported on the temperature difference over different surfaces resulting in urban heat islands. These are characteristic of most North American cities fo at least part of the year. Even in th new town of Columbia, Maryland, wher efforts to reduce the heat-island effec have been made, a measurable hea island has already been detected b Landsberg *(1969)*. Surface temperatur values measured from a helicopter, using infrared instrumentation over Columbia on a sunny morning, recorde differences of up to 8.5°C between forested and builtup areas.

Together, the influence of topograph and land use were thus recognized major contributors to topoclimatic differences within our study area. Th problem was to determine which specif subvariables of topography and land us had the greatest effect on overheatin underheating, and moisture. In addition, these subvariables had to be mea urable from existing and easily available data sources.

Topography.—The subvariables of topography having major effects on topoclimate are slope, aspect, and elevation with respect to sun and wind. The relative differences of sun and wind in turn have major impacts on overheating and underheating.

Effects of topography on wind can be of an active or passive nature. For example, an active topographic influence results from differences of air temperature and pressure, which causes cool air to flow down slopes. This phenomenon is known as katabatic wind. Passive effects of topography on wind are demonstrated by the behavior of an airstream over or around an obstacle.

In New England, exposure to strong northerly winter winds increases convective cooling. By avoiding windward slopes, summits, and large unprotected open spaces, convective cooling can be minimized. Topographic features such as low-lying or basin areas surrounded by higher elevations should also be avoided because they induce drainage of cool air, which is a prime cause of frost and fog formation *(Critchfield 1966)*.

Topography has a major influence on the total solar radiation (insolation) that a site receives. The amount of solar radiation received by a surface is determined by: (1) compass orientation, which determines the number of hours of sunshine received and the time of day when it is received; (2) the slope of the surface, which determines the amount of energy received per unit area; (3) the shadowing effect of adjacent relief, which blocks out portions of direct sunshine during the day; and (4) the relative elevation of the surface above sea level, which reflects the reduction of atmospheric absorption of incoming radiation.

Significant differences in solar radiation receipts resulting from topography have long been recognized, particularly in agriculture. Benefits from reduced heating costs to homeowners and industry can be achieved by locating developments where maximum amounts of solar radiation are available during underheated periods *(Olgyay 1963)*.

Calculating the distribution of solar radiation has been accomplished by using a computer program developed by Williams and others *(1972)*. Data input requirements are a grid of elevations, the solar declination, latitude, transmissivity, and day of the year. Direct, diffuse, and total global radiation can be calculated, as well as absorbed radiation if albedos are specified at the grid points. A contour map is produced by using the Harvard SYMAP program or a similar contouring program that geographically locates the distribution of solar radiation.

Moderating effects of land use. — Grass, pavement, soil, or trees, differ widely in their ability to conduct and store heat. Forests and buildings also have significant effects on local winds. Some surfaces, such as forest canopies, tend to moderate topoclimatic stresses by minimizing extremes. Natural opportunities to control extreme wind velocities and temperatures should be taken advantage of wherever possible.

Recognition and use of moderating factors is included in our assessment by differentiating between various land uses. Forests or even a few rows of trees will greatly reduce wind speed. Based on 10 years of wind records at a height of 4.6 m inside and outside a maple-beech-birch forest, the wind speed in the forest was less than 50 percent of the speed outside for 11 months of the year *(Zon 1941)*. In fact the reduction of winds by 50 percent reduced residential heating requirements by 30 percent. Critchfield *(1966)* noted that the major climatic effect of trees is roughly proportional to the density of the forest cover, but forest can modify the climate of adjacent areas as well. Generally it is assumed that the downwind zone of protection from winds offered by trees is equal to 20 times the height of the tree barrier.

In the model, two categories of forest are identified to reflect their moderating climatic effects: (1) forests with a crown density greater than 80 percent and a height greater than 41 feet, and (2) forests with a crown density between 30 and 80 percent and height between 20 and 41 feet. Although it was recognized that a greater differentiation of forests into hardwood and softwood categories would improve the accuracy of the assessment, we believed two forest categories were sufficient for metropolitan planning purposes.

Nonforested areas are divided into two other categories to reflect differences in their heat absorptivity and conductivity: (1) densely urbanized areas with large amounts of paving, which increase the stress of overheating, and (2) remaining open lands believed to have little moderating or stress-increasing effects on topoclimate.

Numerous other subvariables were investigated, but were not incorporated into our assessment chiefly because we wanted to keep the procedure as simple as possible and still provide sufficiently accurate information to aid those making planning decisions. The influence of major water bodies and extreme differences in elevation are special instances where new subvariables would be required. Other topoclimatic conditions, especially those relating to city climates and air pollution, were not considered in the procedure.

Procedural-framework

Although space does not permit us to go into sufficient detail to explain the intricacies of the assessment procedure, we can provide a general overview. The procedure can be organized into three basic steps.

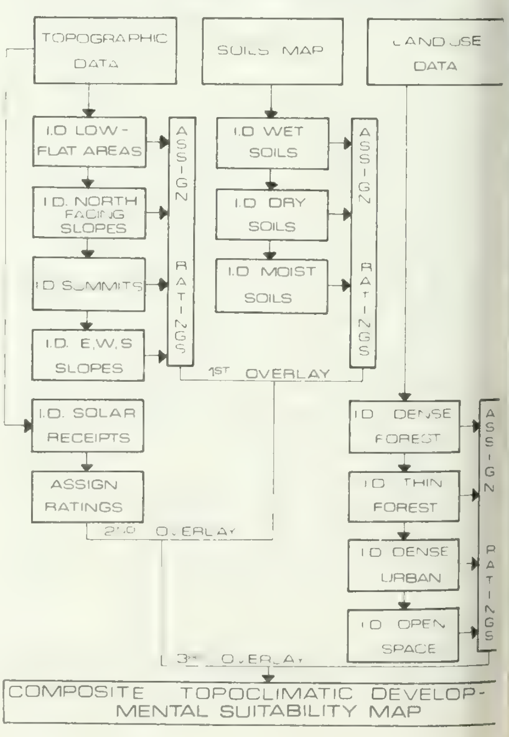
1. Data collection.—Topographic data may be obtained manually from USGS topographic maps or directly from magnetic tape available from the USG National Cartographic Center at Resto Va. Land-use data may be obtaine from interpreted aerial photographs an soils data from detailed SCS soil maps.

2. Source-map preparation. — Th second step is really a two-stage procedure. Once the data have been co lected, they must be put into a mappe format, which is then digitized an stored on magnetic tape. Using th COMLUP computer mapping system, a described by Ferris and Fabos *(1974)* and the assessment procedure presente here, a series of source maps are the produced.

3. Overlay procedure.—The third an final step produces a series of composit overlay maps culminating in a composite topoclimatic developmental-suitabi ity map. Again, the computer is use to overlay the maps.

A procedural flow chart (fig. 1) show the assessment process from data ac

Figure 1.—Topoclimate developmental sui ability assessment procedure.



quisition to the final topoclimate suitability assessment map. Preparation of each source map and the overlay procedure will be briefly described next.

Source-Map Preparation

The topoclimate developmental-suitability-assessment map is generated from four source maps: (1) a topograhic map, (2) a land-use map, (3) a soils map, and (4) a solar-radiation receipt map. Source map information is digitized into computer manipulatable format so that overlays or composite assessments and evaluations can be made.

The following discussion briefly outlines the general procedures for preparing each source map, using the town of Burlington, Massachusetts, for demonstration purposes.

Topographic source map. — Using topographic data from one of the previously identified sources, we identified low-lying, relatively flat areas, summit areas, north-facing slopes, and remainng areas of south, west, and east slopes. These areas may be identified by interpreting 10- or 20-foot contours or with computer assistance using a 200- or 500-foot grid network. Low-lying, relatively flat areas are given a 1_f rating because potential fog and frost conditions may exist in these areas. Summits are given a value of 1_s because potential high wind conditions may be expected n these areas. North-facing slopes are given a value of 1_n because this orientation to winter winds is least suitable for comfort and heating in cold temperate climates. All other areas are assigned a rating of 2, which reflects their minimum influence on topoclimate; the higher ratings indicating the most desirable areas for development.

Land-use source map.—Land use can have a significant effect on local topoclimate. These differences are reflected in he following land-use aggregations. All urban/commercial/industrial uses are given a 1_u value because of their potential for overheating in summer. Forested areas are recognized for their moderating effect on climate in both winter and summer by assigning a value of 3 to those areas having a crown density between 30 and 80 percent and a height of 21 to 41 feet. A value of 4 is given to forests with a crown density greater than 80 percent and height greater than 41 feet. Remaining open space and crop and pasture lands are considered to have no significant moderating effect and are given a value of 2.

Soils source map.—The tendency of moist soils to remain cooler during the day and warmer during the night is included in the assessment by giving moist soils (soils with moderate to slow percolation) a value of 2 and dry soils (soils with excessive percolation) a value of 1_d. Soils with a seasonally high water table or very poorly drained soils are given a value of 1_w. These wet soils, in combination with relatively low-lying and flat areas, are susceptible to fog and frost in relation to other areas.

Solar radiation source map. — The radiation source map depicts the distribution of global radiation for a given period and transmissivity over an area at a given latitude, the topography of which is specified. Areas of high, medium, and low global radiation are given values of 3, 2, and 1_r respectively for winter since maximum radiation is needed at this time. For our study areas a maximum difference of 98 langleys per day between areas for 21 December were obtained, assuming a sunny day. This range was divided into three categories of 0 to 30, 31 to 60, and 61 to 98 to reflect the relative contribution of solar receipts during underheated periods.

During the summer a minimum of solar radiation is needed. If desired, the high, medium, and low areas of summer solar receipts can be given values of 1_{sr}, 2, and 3 respectively.

In some regions of little topographic variety, the difference in solar receipts is relatively insignificant (less than 30 langleys per day). In other cases the differences in solar receipts are so large that the solar-radiation values become the major contribution to topoclimate differences.

Composite Overlay Preparation

First, the topographic source map is overlaid with the soils source map. Areas possessing a high water table or poorly drained and low-lying and flat are susceptible to fog and frost.

The topographic and soils source map is next overlaid with the solar-radiation source map. Potentially overheated and underheated areas can now be identified. Overheated areas will be identified by combinations of maximum summer solar receipts and dry soils. Underheated areas will be areas of minimum winter solar receipts, dry soils, and exposure to cold winter winds along ridges and north-facing slopes.

Finally the land-use source map is overlaid with the series to produce a final composite topoclimate suitability map. The land-use source map reflects the effect forests and heavily builtup areas have on topoclimate. The moderating effect of a forest improves both a potentially overheated area as well as an underheated area. Surfaces that are paved and highly urbanized exacerbate the overheating problem:

In summary, the following subvariables are identified and rated:

Topographic	*Rating*	*Land use*	*Rating*
North slope	1_n	Urban	1_u
Summit	1_s	Open rural	2
Low & flat	1_f	Forest (thin)	3
E,W,S slopes	2	Forest (dense)	4

Solar	*Rating*	*Soils*	*Rating*
Low	1_r	Dry	1_d
Medium	2	Wet	1_w
High	3	Moist	2

After all four maps have been overlaid, the total range of values for an area with little topography is from 4 to 9. This condition results when there is no significant effect of topography on solar receipts, and the entire study area receives a single value of 1. However, in an area with significant topography, the composite value range is from 4 to 11. Both value ranges are divided into three suitability categories to reflect a hierarchy of suitability: (A) most suitable, (B) marginally suitable, and (C) least suitable.

For an area with little topography, the influences of land use (such as forests) and of soils become dominant, resulting in the following suitability categories:

8 to 9 — most suitable (A)
6 to 7 — marginally suitable (B)
4 to 5 — least suitable (C)

For an area with significant topography (when the solar ratings are from 1 to 3), the suitability categories are:

9 to 11 — (A)
6 to 8 — (B)
4 to 5 — (C)

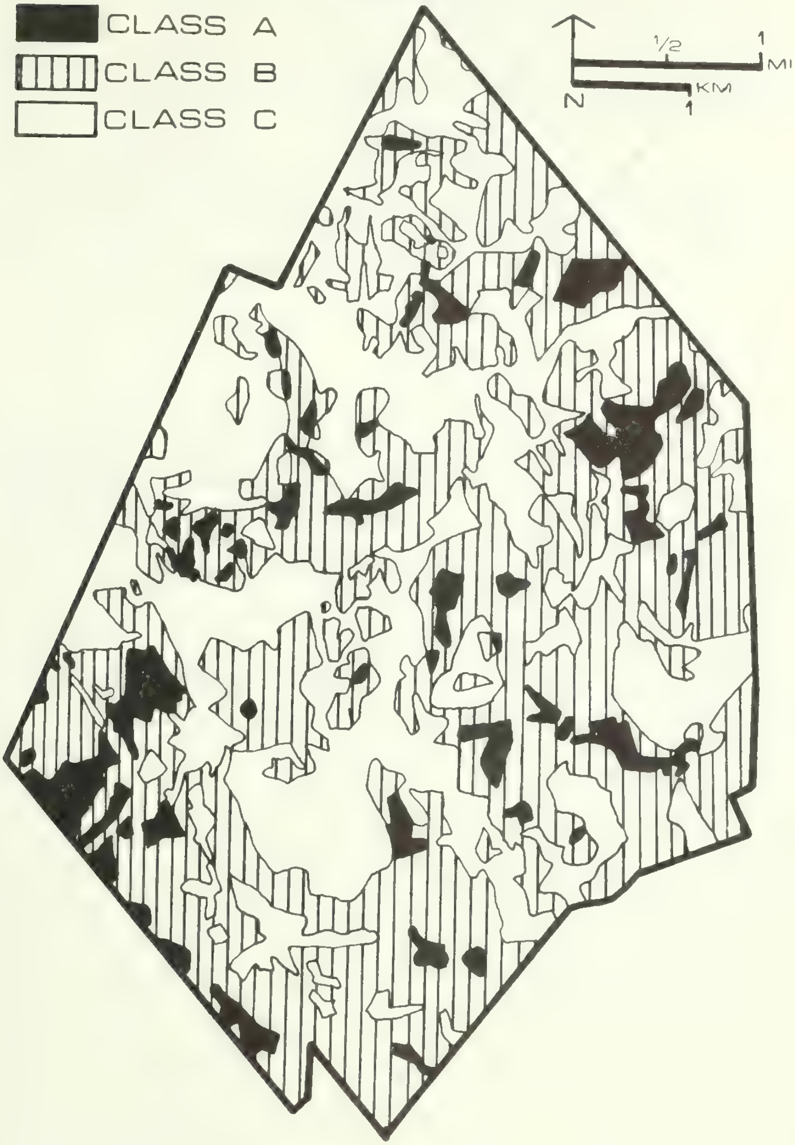
For the Burlington area (in 1971) 9 percent of the area was given a rating of A, 52 percent a rating of B and 39 percent a rating of C. Further work on identifying which suitability categories have been most intensively developed since 1952 is presently under way.

RESULTS

The composite topoclimate suitability map (fig. 2) shows the distribution of topoclimates in Burlington, Massachusetts. Topoclimate differences in Burlington are minimal primarily because there is little topographic change within the town. Most of the topoclimate differences result from the distribution of land-use types. Dense forest areas contrast sharply with the extensively built-up areas along Route 128.

In addition to mapped output, tabular information on each parcel is also available. This information is extremely important because it provides an account-

Figure 2.—Topoclimate developmental suitability map, Burlington 1971.



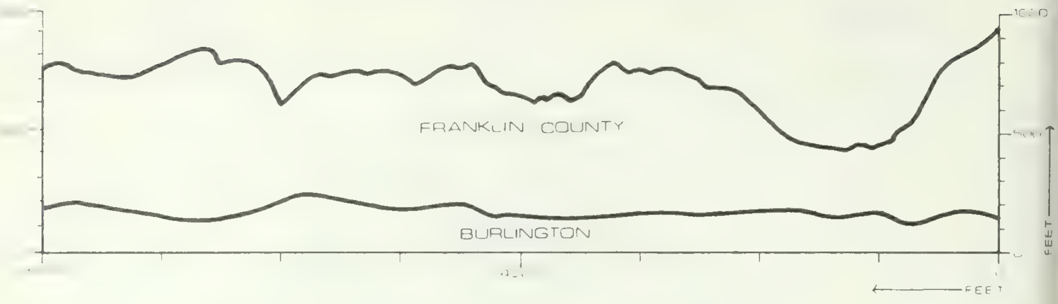
ng of the various values received by the arcel. For example, a developer has ubmitted a subdivision plan to Burling-on in a C-rated area and wishes to now why the town fathers tell him hat the site is topoclimatically least uitable. The developer may then be hown a map and a print-out with the ollowing information:

Parcel No.	*Topo*	*Land use*
18	1_n	2

Soils	*Solar*	*Total*	*Rating*
1_d	1_r	5	C

From this information, both the town and the developer know that the site is on a north-facing slope, in a rural open non-forested area with dry soils and a

Figure 3.—Topographic cross-sections of Burlington and a portion of Franklin Co., Massachusetts.



minimum amount of solar radiation receipts in winter. Such information indicates increased heating costs and a reduced outdoor comfort season to the potential homeowners; increased costs to the town for winter road maintenance for sand, salt, and snow removal; and increased costs to the developer through a reduced construction season.

The significance of topographic change to topoclimate can be seen between two areas in Massachusetts. The range in Burlington is from 135 langleys to 170 langleys for the 21 December. For a portion of Franklin County the range is from 100 to 195 langleys under similiar conditions except for topography. A comparison of the topography of the two areas is shown in the topographic cross-sections (fig. 3). It is clear that the greater range in solar radiation receipts in Franklin County is the result of the greater relief in that area.

CONCLUSIONS

The purpose of this paper has been to describe a topoclimate developmental suitability assessment procedure. The procedure has been applied to Burlington, Massachusetts, and partially to an area in Franklin County, Massachusetts. Topoclimatic differences were mapped, using a computer-based mapping system.

Although complete field checks with the mapped assessments have not been completed, preliminary comparisons are encouraging. Instrumentation to measure wind speed and solar radiation is now being set up in Franklin County by the Department of Mechanical and Aerospace Engineering at the University of Massachusetts. These data will be used to test the accuracy of the present procedure and to quantify potential cost savings among identified topoclimates.

The information provided by the procedure will be useful to decision-makers who must make land-use-management decisions. Once areas that minimize the long-term costs of maintenance and maximize the intrinsic capability of the landscape to provide health and comfort have been identified, planning decisions may then anticipate and reflect present and future costs prior to actual development.

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METROPOLITAN ACOUSTIC ENVIRONMENTS AND USE OF VEGETATION IN NOISE CONTROL

Range of Sound Levels in the Outdoor Environment

by LEWIS S. GOODFRIEND, *Lewis S. Goodfriend & Associates, 7 Saddle Road, Cedar Knolls, N. J. 07927.*

ABSTRACT.—Current methods of measuring and rating noise in a metropolitan area are examined, including real-time spectrum analysis and sound-level integration, producing a single-number value representing the noise impact for each hour or each day. Methods of noise rating for metropolitan areas are reviewed, and the various measures from multidimensional rating methods such as the Composite Noise Rating are examined, along with the trend towards single-number rating schemes. The reliability of the various noise-measurement and evaluation methods is discussed in terms of planning needs.

THE RANGE OF OUTDOOR NOISE levels is extremely large, ranging from the tranquil quiet of the wilderness to the noisy urban environment. Some people live within 15 feet of the right-of-way of major highways, where the outdoor noise levels may be above 90 dB(A). Many suburban and suburban rural residents live along the right-of-way of major interstate highways and local freeways where even at 100 or 200 feet the sound levels approach 90 dB(A). A far larger number of people live in the rural, suburban, and urban areas more distant from the transportation systems. They are exposed to what, for most of the residents within each area, are noise environments that are quite acceptable. Even here the sound levels range from below 30 dB(A) to as high as 65 or 70 dB(A).

Some specific examples will show the nature of these noise exposures. In one remote rural farming community, the range of residual ambient sound levels across the entire acoustical frequency spectrum for a 24-hour period remained below 41 decibels (fig. 1 and fig. 2). I this same community, the intrusive (L_{10} A-weighted sound levels, the level b- low which 90 percent of all levels wi occur, was only 43 decibels (fig. 3).

For the suburban rural environmen the residual ambient sound levels st have some indication of the flatness wi frequency while the L_{10} sound levels as function of frequency exhibit the spe trum of vehicular traffic (fig. 4).

In the urban environment, both t residual (L_{90}) and the L_{10} levels as function of frequency show the conca bulge in the midfrequency range chara teristic of road traffic (fig. 5).

Even in the urban environment t top ten percent of the levels must be t ones considered intrusive. The intru ions show up with sound levels reac ing peaks as high as 90 dB(A). Ho ever, the duration is short for any giv intrusion (fig. 6).

It is unfortunate that these noi cannot be described in writing becau much is lost in the inability to descr all the dimensions of a sound. How

Figure 1.—Range of summer-day residual ambient noise levels in a rural farming community.

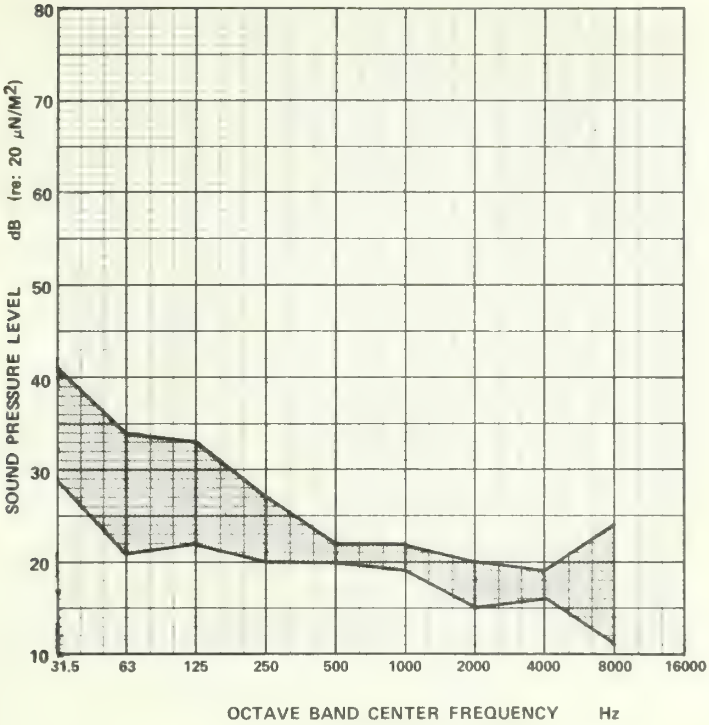


Figure 2.—Range of summer-night residual ambient noise levels in a rural farming community.

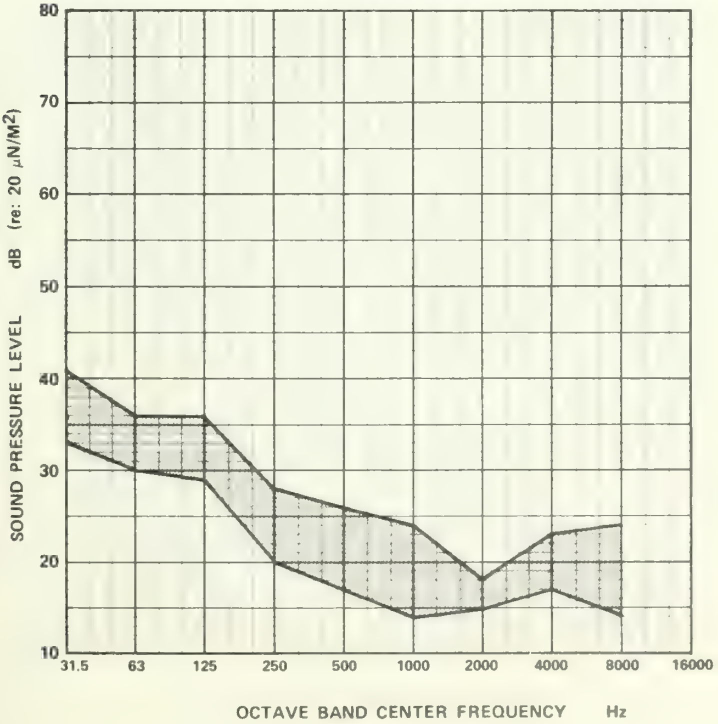


Figure 3.—Statistical distribution of summer-day noise levels in a rural farming community.

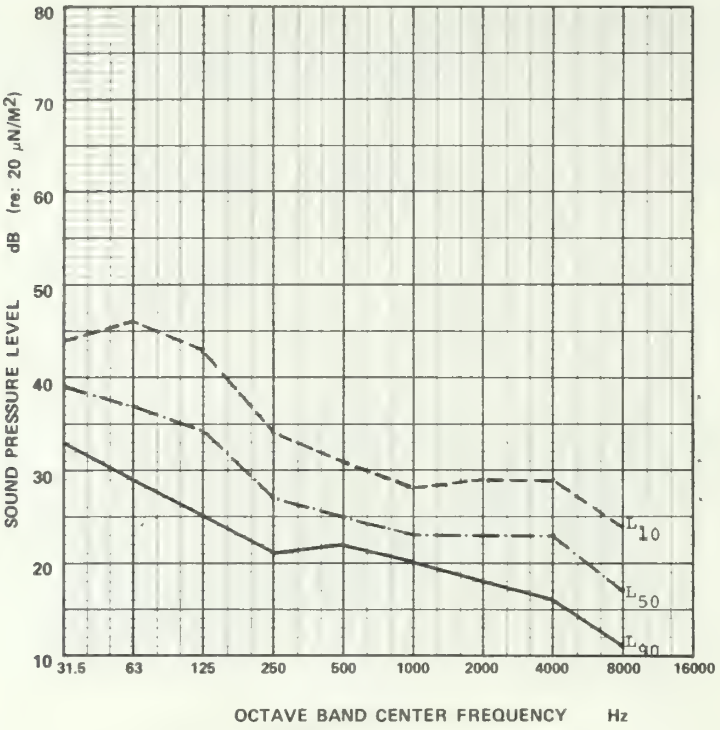


Figure 4.—Statistical distribution of summer-day noise levels in a suburban-rural community.

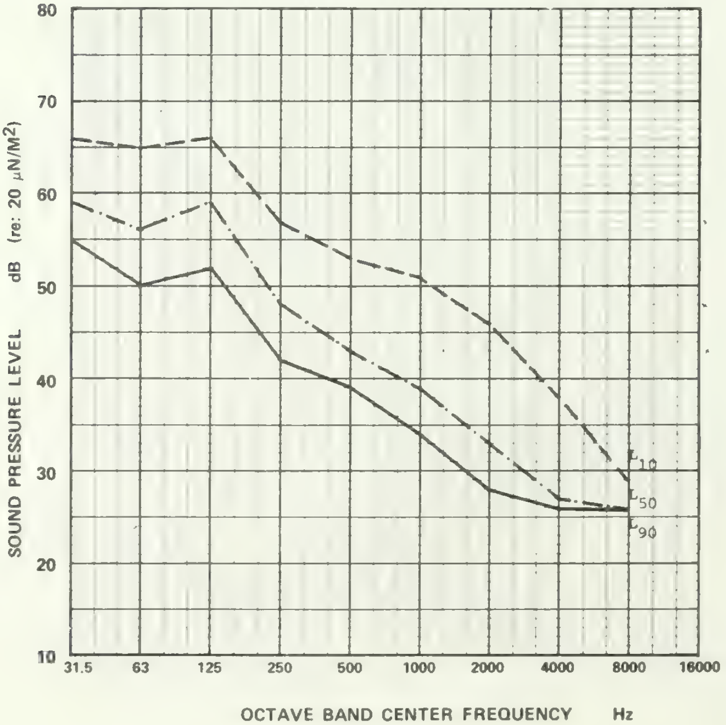


Figure 5.—Statistical distribution of summer-day noise levels in an urban community.

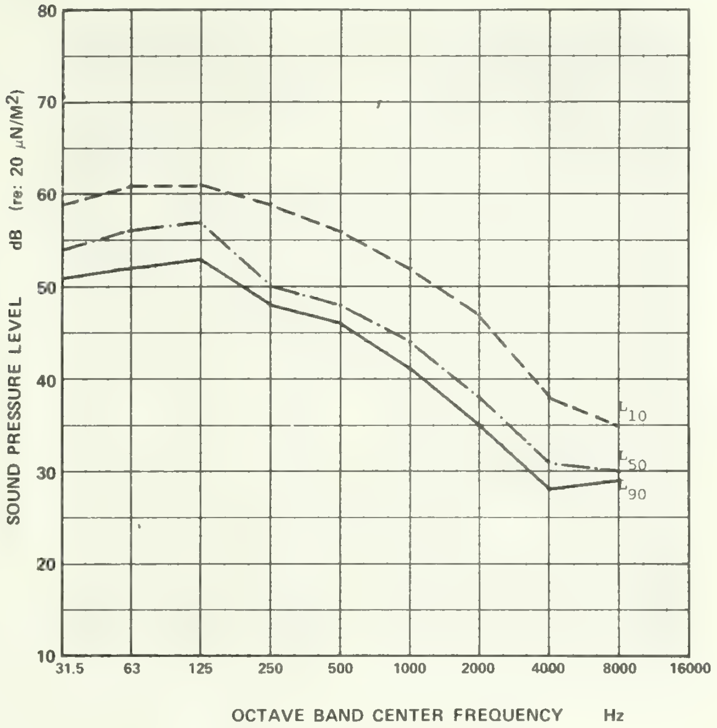
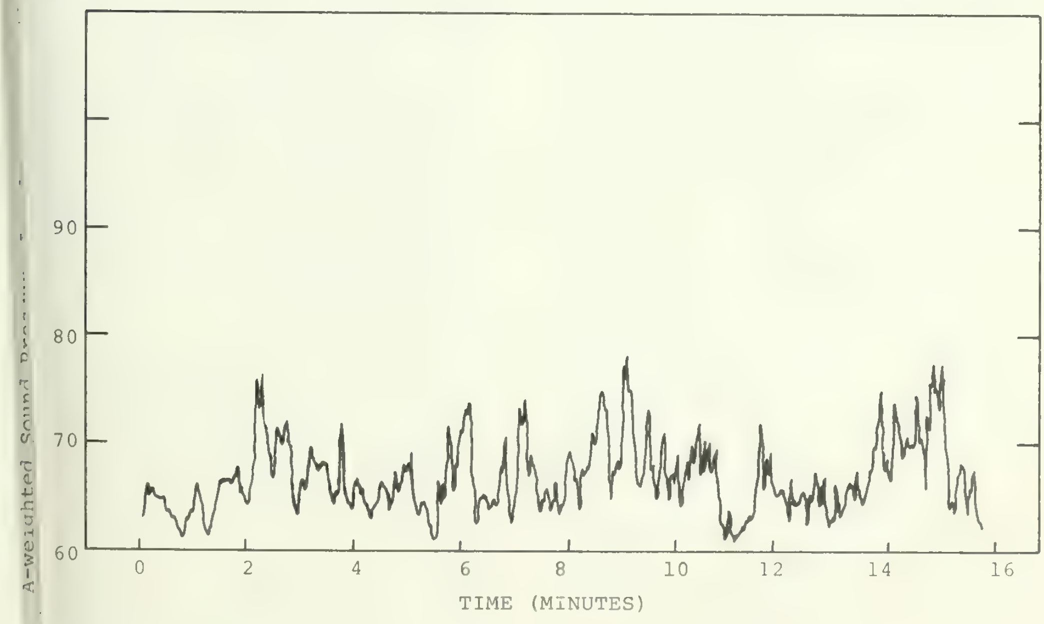


Figure 6.—Time history of the daytime noise levels in a typical urban environment over an 18-minute period, 1:41 to 1:57 P.M.



the pleasant rural summer evening with crickets and peepers producing sound levels in the 40 dB(A) range be compared to the much less acceptable sound of a nearby air conditioner's air-cooled condenser, even though both spectra are rich in high frequency energy. Even more difficult to describe is the difference in the qualities of sounds made by a large heat exchange cooling tower with its water spray and splashing sounds, and the sound of the surf. The acoustical spectra may be quite similar, but one is enjoyed and the other is seldom tolerated, even at sound levels 15 to 20 decibels lower. Of course, one would not exepct to hear the sound of surf pounding the shore in an urban apartment at any sound level. It actually occurs at levels above 60 dB(A) in homes along the shore line in many beachfront communities.

There are many other groups of sounds having similar spectra and levels that range from the totally unacceptable to the pleasurable. It is clear from much of the research on the effects of noise on man that context and associative factors play major roles in the acceptability of sounds that do not interfere with speech communications or sleep. However, as background for creative activity, some high-level noise environments are considered satisfactory while low-sound-level environments containing information inimical to the listener are distracting and annoying.

Even in the residential context where routine family activity is all that is going on, certain sounds at almost any level have undesirable connotations. A new industrial plant that can just be heard, even though it is well below code requirements, would be acceptable in many communities with existing industry. It may not be accepted in a community if it were to move into an industrial zone that has not been occupied previously. The lack of acceptance, even of low-level noise in this case, obviously has social connotations.

RATING NOISE

Can we somehow rate these noise environments in terms of human acceptability? A look at some of the methods tried will indicate the success. It has been common at various times during the past 40 years to characterize noise environments by both single-number values, such as the widely used A-weighted sound level, and by the sound-pressure level in each octave band.

The A-weighted sound level was one of the earliest tools used to rate city noise. However, in the late 1940s the octave band levels were considered necessary to correctly characterize any sound. By 1970, those working in environmental noise were again almost exclusively attempting to use the A-weighted sound level for rating noise environments. Numerous schemes have been developed to measure the A-weighted sound level temporal statistic at one or more points in a community on a sampling statistics basis, and to use these statistics to define the noise climate in some way.

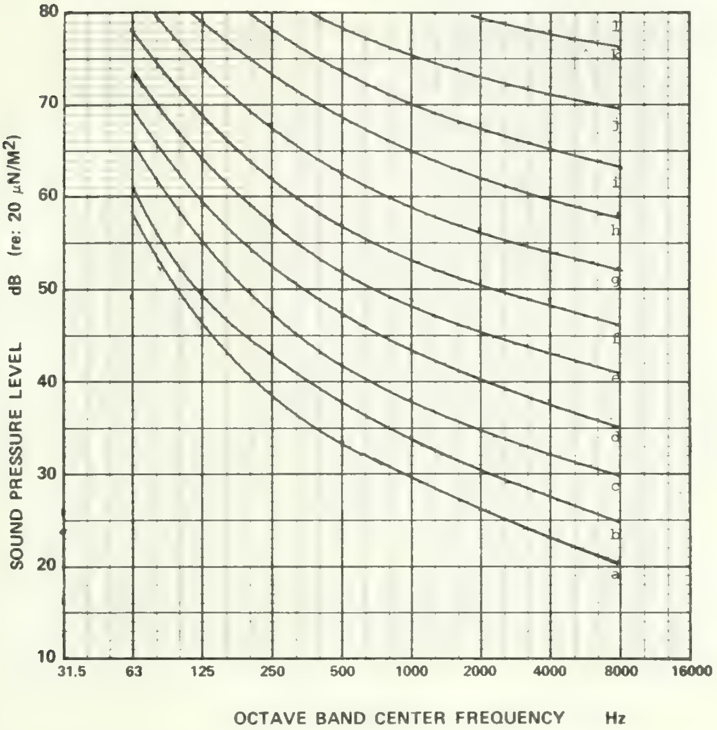
However, a close examination of the factors that influence human response will show why most proposed single-number rating schemes will fail in a but the simplest case. When rating methods are required to define the a ceptability of an environment for res dential use, be it one family houses, o apartments, or one or more large buil ings, they often fail to consider a fe susceptible individuals or people wh carry on creative tasks at home, su as writers, composers, editors, a students.

A look at some of the more wide used current methods of rating noi environments should show the natu of the problem and the reason why a how each particular scheme fails—a they do fail.

Composite Noise Rating

This first appeared in 1954 in the Force's Handbook of Acoustic No

Figure 7.—Level rank curves for use in rating residential noise environments. The spectrum to be rated is drawn on the chart and the letter in the highest zone between the curves is assigned as the level rank. The level rank is adjusted according to table I to obtain the Composite Noise Rating or CNR.



ontrol and was later revised in a paper y Stevens, Rosenblith, and Bolt *(1955)*, nd by Harris *(1957)*. The basic idea to compare the spectrum and levels of noise with a set of octave band con- urs labelled with lower case letters ig. 7). The highest contour penetrated called the *level rank* for the noise. The vel rank is then changed one rank (the uivalent of a five-decibel step) for ch of a series of adjustments related season, time of day, ambient levels, ration, and character of the noise.

The resulting adjusted level rank is ven a capital letter designation called te *Composite Noise Rating* (CNR). e of the curves (fig. 7) allows an eimate based on experience to be made the nature of community response by mparing the CNR to a table or curve predicted response (fig. 8). The method is quite good, although it is claimed by Bishop *(1967)* to be less sensitive than it might be because of the five-decibel steps used. However, it has proved most effective where the correct data are supplied, particularly the duration of the intruding noises. Major drawbacks in using the CNR were the need for octave band spectra at several places in the community, along with duration information. This method was later adapted for an aviation noise response-prediction scheme jointly by the military and FAA *(1964)* for a land-use planning evaluation scheme for use around airports.

Community Noise Equivalent Level

This was developed by Wyle Laboratories *(1971)* for application to the airport noise monitoring problem. When

Table 1.—Correction numbers to be applied to noise level rank to yield Composite Noise Rating

Influencing factor	Correction number
1. Background noise:	
Type of neighborhood:	
Very quiet suburban	+1
Suburban	0
Residential urban	—1
Urban near industry	—2
Near heavy industry	—3
2. Temporal and seasonal factors:	
a. Daytime only	—1
Nighttime	0
b. Repetitiveness	
Source operates 20% of time in an 8-hour period	—1
Source operates 10% of time in an 8-hour period	—2
Source operates 2% of time in an 8-hour period	—3
c. Winter	—1
Summer	0
3. Character of the noise:	
a. Spectrum character:	
Continuous spectrum	0
Pure tone	+1
b. Peak factor:	
Smooth time character	0
Impulsive	+1
4. Previous exposure:	
None	0
Some	—1

Figure 8.—The predicted response of a community uniformly exposed to noise levels plotted on the level rank curves and adjusted according to table 1.

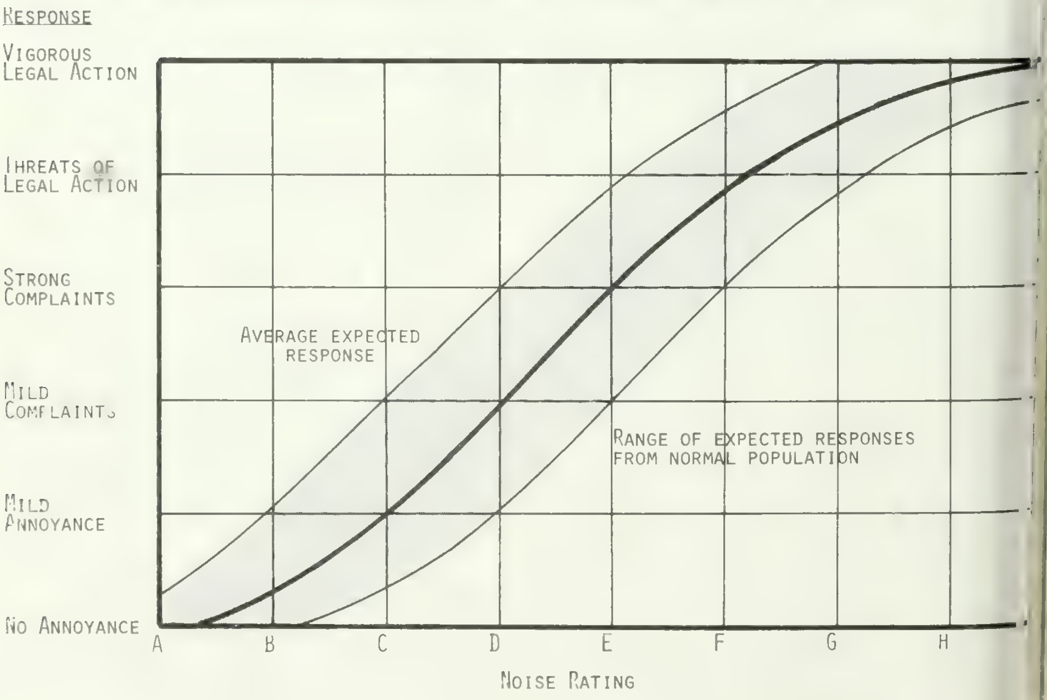
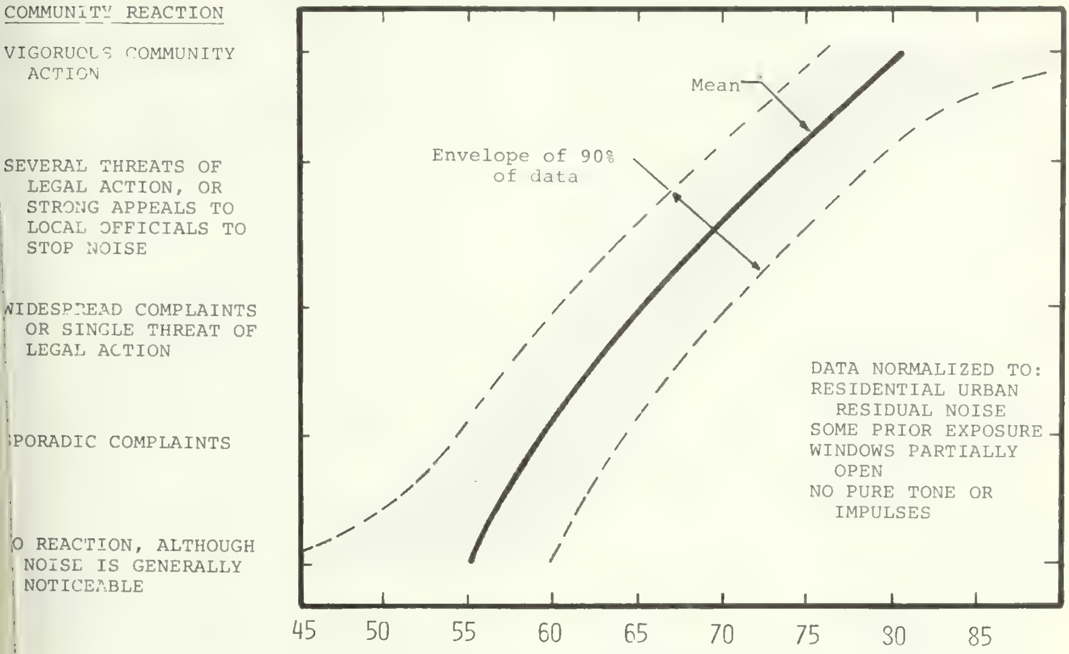


Figure 9.—The predicted response of a community may be obtained from the energy equivalent sound level in three periods—day, evening and night—using the equation shown below the figure. The figure shows the predicted response after adjustment according to table I.



$$CNEL = 10\ Log\ (\frac{1}{m+n+l})\ [\sum_{i-1}^{m} Antilog\ (DL_{10}/10)_i + 3 \sum_{i=1}^{n} Antilog\ (EL_{10}/10)_i + 10 \sum_{i-1}^{l} Antilog\ (NL_{10}/10)_i]$$

Where m, n, and l are the number of intrusive noise level values for day, evening, and night-time sampling periods, respectively.

eamining the problem of using a single nmber to describe the noise impact on aommunity from any kind of source, ty found that the CNEL could be ud as the evaluator of the physical eposure of members of the community. T CNEL is essentially the average of th hourly energy averaged A-weighted sond levels in three periods; day, evenin and night. This may be computed frn the data by using the hourly L_{eq} (f. 9).

he CNEL is then adjusted in the ae way that the Composite Noise Rang was obtained and is normalized o e following conditions:

- Residential urban residual noise.
- Some prior exposure.
- Windows partially open.
- No pure tones or impulses.

These data may then be compared to table or chart to evaluate the probable community response (fig. 9).

ISO Draft Recommendation No. 1996

This suggests a method of measurement of noise, corrections to the measured level, and a means of using this corrected or rating sound level, for comparison with a community noise criterion *(ISO 1970)*. The community noise criterion considers various environmental acceptability factors.

The ISO draft recommends that noise should be measured by using a precision sound-level meter set at the A-weighting network and "fast" response. If the noise varies with time (as is the usual case for most nonindustrial environments), the rating is based on the energy equivalent level, L_{eq}. L_{eq} is defined as the "energy mean" of the noise, and for sampled data may be represented as a continuous, unvarying signal resulting in the same total energy each hour, or each day, as produced by the actual noise being measured.

The ISO recommendation suggests adding values to L_{eq} dependent upon the character of the noise and its duration, which results in a better estimate of the community's response to the noise. The resulting value is termed the "rating sound level", L_r.

The "rating sound level" might be considered the A-weighted sound level of a steady noise that does not contain any tonal or impulsive characteristics and produces the same community response. Hammering and riveting, it is suggested, are impulsive characteristics and require that +5 dB(A) be added to the rating sound level.

Two other methods for rating noise have been widely used. These are the Effective Perceived Noise Level in EPNdB, and the Noise Pollution Level.

Effective Perceived Noise Level

This is an extension of the aircraft noise rating method based on the noisiness curves developed by Kryter *(1959)* and applied by him to a broader noise-evaluation technique. It is basically a duration adjusted perceived noise level. It requires the use of the octave band spectra as input. The noise in question is evaluated on a band-by-band basis, using curves or a chart of noy — for noisiness — values for the level in each band. A summing scheme similar to that developed by S. S. Stevens *(1961)* in his loudness computation method, yields a summed noisiness value which may then be converted into the perceived noise level in PNdB. Adjustment for duration and pure tone content are made, and the result is the Effective Perceived Level

Noise Pollution Level

This appears, at first glance, to hav the right balance of the factors of leve and duration to provide useful measur of noise impact. It was developed by D W. Robinson *(1969)* who carried out thorough analysis of a number of noise rating methods and proposed that an noyance was related both to the tota distribution of energy through the da — i.e., the exposure of the individual t the noise — and to a factor governed b the variation of level. He defined th Noise Pollution Level NPL = L_{eq} + 2.56 where σ is the standard deviation of th measured signal, assuming its distrib tion of levels as gaussian. This appea to be handy and rank orders numero environments reasonably well.

However, the scale turns out to b somewhat compressed. Wyle Labor tories *(1971)* found that busy downtow areas had NPL values only slight higher than suburban residential area judged by the public to be considerab less noisy. The strange result deriv from the fact that downtown, the stan ard deviation is rather small — it is co tinuously noisy — although the L_{eq} i high, but out in the suburbs L_{eq} is lo but the standard deviation is high, neighbors' cars and delivery vehic come and go, and the sounds of childr at play add to the range of σ. Final since community noise is not gaussi the standard deviation has little or meaning here.

Department of Housing and Urban Development Noise Criteria

The United States Department Housing and Urban Developm (HUD) has set acceptability criteria new housing. The external noise sta ards are:

Category	*Standard*	*Environment*
Clearly acceptable	Does not exceed 45 dB(A) more than 30 minutes per 24 hours.	The noise exposure is such that both the indoor and outdoor environments are pleasant.
Discretionary: normally acceptable	Does not exceed 65 dB(A) more than 8 hours per 24 hours.	The noise exposure is great enough to be of some concern, but common building construction will make the indoor environment acceptable, even for sleeping quarters, and the outdoor environment will be reasonably pleasant for recreation and play.
Discretionary: normally unacceptable	Exceeds 65 dB(A) 8 hours per 24 hours; loud repetitive sounds on-site.	The noise exposure is significantly more severe so that unusual and costly building constructions are necessary to ensure some tranquility indoors, and barriers must be erected between the site and prominent noise sources to make the outdoor environment more tolerable.
Clearly unacceptable	Exceeds 80 dB(A) 60 minutes per 24 hours; Exceeds 75 dB(A) 8 hours per 24 hours.	The noise exposure at the site is so severe that the construction costs to make the indoor environment acceptable would be prohibitive and the outdoor environment would still be intolerable.

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ay-Night Level

The L_{dn} is equivalent to the $L_{eq_{24}}$ with 10 dB weighting applied to the equiv-ent level during the nighttime hours. he L_{dn} is defined as follows:

$$L_{dn} = 10\log\frac{1}{24}[15(10^{Ld/10} + 9(10^{Ln/10})]$$

$= L_{eq}$ for the daytime hours (0700 to 2200)

$= L_{eq}$ for the nighttime hours (2200 to 0700)

The 10 decibel weighting was derived fom several considerations: prior use o a nighttime weighting in other de-siptors, and a normal difference in dytime and nighttime levels of 10 decibs. Descriptors such as CNR, NEF, NNEL all use a weighting on the order o 10 decibels to adjust noise produced dring the night to produce a more sere reaction on their response scales. The correction in these rating schemes, as well as L_{dn}, is designed to protect persons from possible sleep interference.

The assumption that equivalent sound levels for daytime and nighttime usually differ may be a valid one for urban and suburban communities, but in a rural suburban or rural community, this is rarely the case. Sound levels in rural areas are determined by distant events since local activity is low. Local activity causes the difference in daytime and nighttime levels, and an area lacking this activity will experience very little change from day to night with perhaps an increase at night due to insects. It is in this case that the usefullness of L_{dn} as a descriptor of impact is limited. A noise source may operate solely during the day, at levels comparable to the daytime ambient of, say, 45 dB(A); and a similar level at night of 45 dB(A) may be produced by insects, resulting in an L_{dn} of 55. However, the EPA literature indicates that this level produces activity interference outdoors. Clearly the noise source is not causing the high L_{dn}, which indicates that care must be used whenever L_{dn} is used as a criterion.

DISCUSSION

Mathematical modelling techniques have proved useful in predicting the noise of a wide variety of projected facilities. Among the more widely used noise models are those for:

- Power-plant fans
- Cooling towers
- Air discharge and valve noise
- Highway traffic noise
- Railroad noise
- Aircraft

These models and some specially designed proprietary models for power plants and construction sites may be combined with analytical techniques to produce large-scale environmental models. Many models have been developed or modified for computer use. Others make use of nomographs, tables, and charts.

There are many situations where monitoring cannot identify which of multiple noise sources is the major contributor. Also, where changes to industrial plants are to be made or new transportation or industrial facilities are to be built, mathematical modellin of acoustical properties is a useful an reliable predictive technique.

We have shown that the range of ou door noise levels is great, ranging fro less than 30 to more than 90 dB(A) The methods that are close to actu field conditions for rating the accept bility of these various environments in clude factors that account for the soci and geographic situation as well as th spectrum duration and the level of nois No rating system is completely succes ful in rating environmental noise b cause it is difficult to characterize quantify some of the factors that i fluence acceptability.

The final rating of environment noise is always its acceptance or r jection by the community.

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Outside and Inside Noise Exposure in Urban and Suburban Areas

by DWIGHT E. BISHOP *and* MYLES A. SIMPSON, *Bolt Beranek and Newman Inc., respectively at Canoga Park, Calif., and Arlington, Va.*

ABSTRACT.—In urban and suburban areas of the United States (away from major airports), the outdoor noise environment usually depends strongly on local vehicular traffic. By relating traffic flow to population density, a model of outdoor noise exposure has been developed for estimating the cumulative 24-hour noise exposure based upon the population density of the area. This noise model has been used to provide first-order estimates of noise exposure in urban areas of this country. The model also can be used to estimate the variation in noise levels in communities and to plan community noise surveys. Field measurements at 100 locations throughout the country have shown good agreement with this model.

THE OUTDOOR NOISE environment in urban and suburban areas in this untry is due to many different noise surces of varying frequency content ad temporal characteristics. Actual ise levels and noise exposures vary er a considerable dynamic range. wever, because of the prevalence of smilar major sources of noise, one can epect many similarities in noise expsure and in daily patterns of noise expsure throughout the country. These silarities suggest that there should be gd likelihood of developing useful mdels for predicting the noise envirment for different neighborhoods thoughout the country.

Because of the well-identified and relatvely well-studied impact of jet-aircrft noise and high density freeway trfic noise, rather detailed analytic mdels have been developed for predictn aircraft and highway noise. These mdels are quite accurate for locations etively close to the noise sources. Alhough aircraft operations and freewa traffic produce some of the noisiest uoor environments found in this otry, only a small proportion of the ot population is exposed to these ater intense noise sources. The majority of the population is affected by noise from other sources. A means for defining the noise exposure for this large segment of the population that does not depend upon detailed knowledge of source levels, operating conditions, or identification of specific noise sources is particularly useful for community and land-use planning.

This paper discusses a simple model for estimating the noise exposure in urban and suburban areas not located near airports or major freeways. The paper also discusses measurements made to confirm and verify this model and also provide additional information about typical urban outdoor and indoor noise environments.

An emphasis on the outdoor noise environment sometimes obscures the fact that most of us spend much of our lives indoors, and that actually, our noise exposure is not necessarily predicted well from knowledge of the outdoor noise levels alone. Thus, to provide some perspective, this paper also presents a brief comparison of simultaneous indoor and outdoor measurements made in residential areas.

Before describing the noise model and measurements, we should first define the kind of noise measure that we will use. All measurements will be reported in terms of the A-weighted noise level in decibels. This level incorporates a frequency weighting of the noise signal similar to that of the human ear; it thus provides a reasonably good assessment of the noise in terms of people's subjective response to noise.

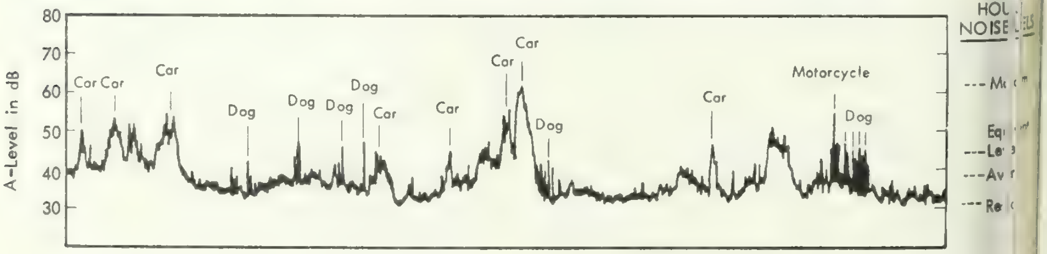
Because of the time-varying nature of the actual noise environment, the temporal aspects of noise must also be considered in selecting a useful scale for measuring the noise environment. Given modern acoustic instrumentation and digital computers, it is now easily possible to develop detailed and exhaustive statistical descriptions of the noise measured over any desired time period, ranging from a few minutes to a few years. However, for many planning purposes, such detail is not needed nor desired. Thus, in this paper the noise environment will be described in terms of the A-weighted *equivalent level* measured over hourly periods or measured during the 24-hour day.

For those not familar with the concept, the *equivalent level* is obtained by "energy" averaging the noise levels occurring over a stated period of time, an hour or day, for example. The equivalent level is equal to the level of a *continuous* noise source that would produce the same energy as contained in the actual fluctuating noise levels occurring over the same time period. Figure 1 shows a graphic level recording of t actual noise levels measured over a sho (14-minute) time. The equivalent lev noted on the figure may be compared the maximum level observed during t period and the "arithmetic" avera level existing over the period. The equ alent level is much more influenced the presence of short duration noise trusions than is the "mean" or "media noise level.

To describe the noise environm over a 24-hour day, the day-night av age level (L_{dn}) measure will be us The day-night average level extends equivalent level concept to the ent 24-hour period, but includes a weight of 10 dB applied to the noise lev measured at night (taken as the per from 10 P.M. to 7 A.M.). This weig ing is applied to reflect the grea sensitivity to noise in residential ar during the night.

Other measures of the noise envir ment are in more or less common and are described in the literature. most community noise environments, correlation of one noise measure another will generally be quite h Thus, with the exception of neigh hoods exposed to discrete high-l noise intrusions (such as neighborh near jet airports), general conclus based on day-night levels or ho equivalent levels will hold for most o noise measures in common use.

Figure 1.—An example of noise-level fluctuations over a short time period.



HISTORY OF NEIGHBORHOOD NOISE, A 14 MINUTE SEGMENT FROM A ONE HOUR RECORD

BASIC MODEL ASSUMPTIONS

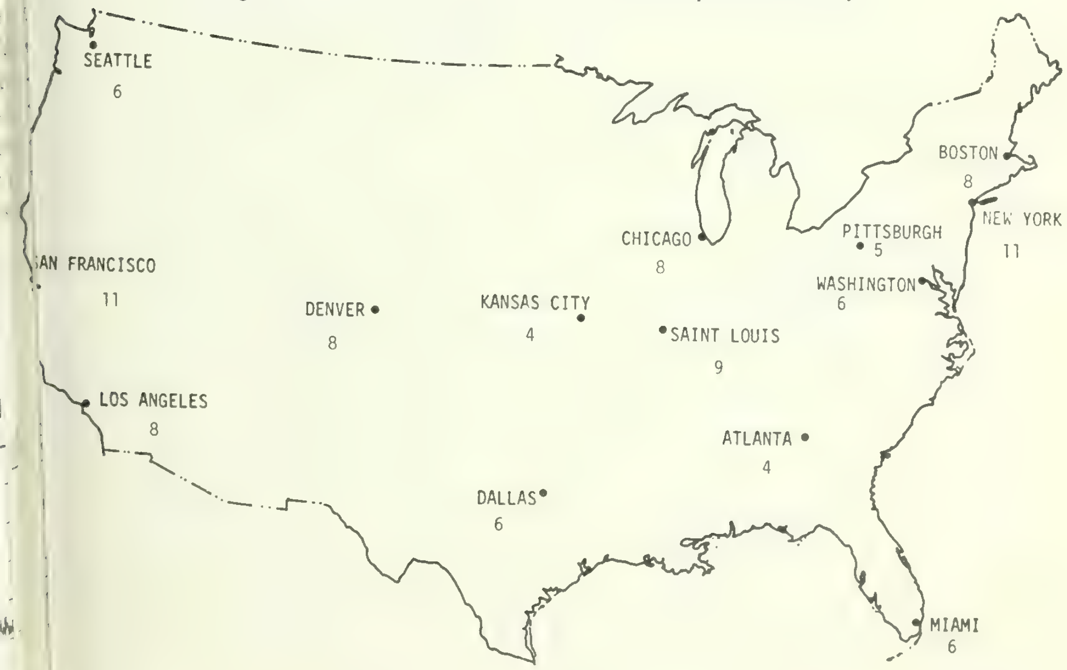
The impetus for developing this noise model arose from the need of the United States Environmental Protection Agency to estimate the outdoor noise exposure for the entire urban and suburban area of the United States. Evidence from community noise surveys pointed out clearly that surface transportation was the most important single contributor to the noise environment. Over a wide range of population densities and of total populations, the number of automobiles per person is almost constant, as is the ratio of trucks in ervice to automobiles in service. Thus he use of vehicles is directly proporional to population density. If nonreeway traffic is considered, the average peed of motor vehicles in urban areas s essentially constant. Application of xisting traffic noise models then sugests that as a first-order estimate, the ommunity noise level should be proportional to 10 times the logarithm of the population density of the community.

This hypothesis was first tested against 30 examples of existing noise data. It was found that the day-night sound level could be correlated with 10 times the logarithm of the density per square mile with an intercept of 32 dB for a population density of 10 people per square mile.

NOISE SURVEY MEASUREMENTS AND ANALYSIS

To obtain more substantiation of this model, a program was set up to measure noise at 100 locations throughout the country. Selection of measurement sites was governed by consideration of the availability of census data, variations in population density, geographic spread of communities, and the need to select sites away from major highways and airports. Figure 2 shows the cities included in the noise survey; the number of sites

Figure 2.—Cities included in the Community Noise Survey.



measured in each city is also shown in the figure.

The central city average density varied among the cities selected from a low of approximately 2,100 in Kansas City to a high of 26,300 in New York City. The field measurements were made in community areas having population densities ranging from slightly over 1,000 per square mile to approximately 90,000 people per square mile.

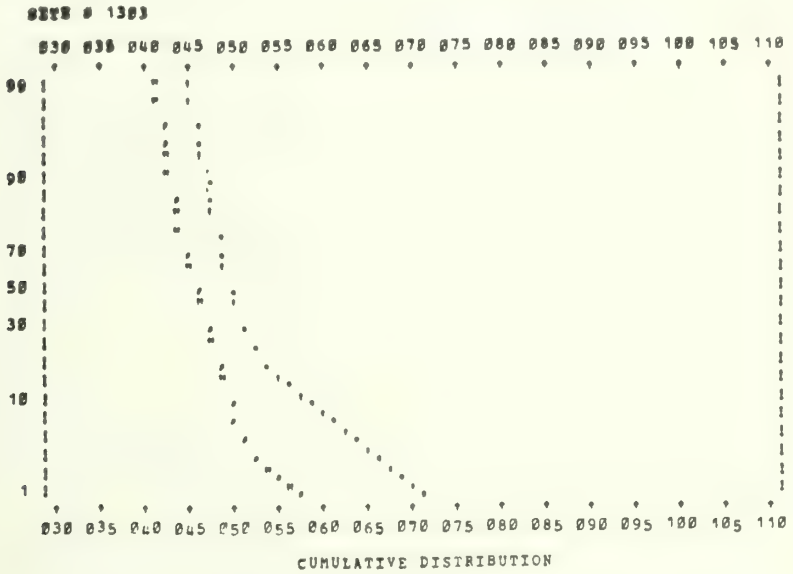
Measurement sites were restricted to areas not closer than approximatel 1,000 feet from major highways an where the estimated noise exposure t aircraft noise was less than an L_{dn} valu of 70 dB. At each site, the microphon was located 1.8 meters from the buildin facade. The microphone was typicall located 1.5 meters above the ground fo single-story residences. For multi-stor residences, the microphone was place at an elevation comparable to occupan height.

Figure 3-4.—Samples of noise data obtained from a 24-hour site measurement.

```
     SITE # 1303

HR   MAX    MIN    NPL    SIG    LEQ    TNI    L1     L3     L5     L10    L20

 1   68.8   42.5   55.0   2.4    48.9   29.4   58.0   54.8   52.2   48.9   48.3
 2   68.8   42.5   50.5   1.6    46.4   26.3   51.2   48.4   47.5   47.2   46.4
 3   71.3   41.3   54.8   2.8    47.7   28.5   60.6   51.4   48.4   46.8   45.9
 4   62.5   40.0   50.0   1.8    45.3   26.9   52.8   48.2   47.0   46.1   45.6
 5   76.3   40.0   54.0   2.7    47.0   25.9   58.7   49.6   46.6   45.3   44.6
 6   68.8   40.0   54.0   2.8    46.8   34.3   56.9   51.1   49.6   47.7   46.0
 7   76.3   42.5   62.3   3.7    52.9   37.0   65.6   58.6   53.5   50.6   48.7
 8   70.0   42.5   56.7   2.7    49.9   37.1   59.7   55.2   53.3   51.2   49.7
 9   71.3   42.5   57.8   2.8    50.6   36.1   60.8   56.2   54.0   51.3   49.8
10   81.3   45.0   67.5   4.2    56.9   40.8   70.0   64.9   59.7   53.7   51.3
11   70.0   43.8   56.7   2.4    50.7   33.0   60.9   53.6   52.0   50.9   49.9
12   83.8   43.8   63.5   3.5    54.6   46.3   63.8   58.8   56.9   54.9   53.4
13   82.5   43.8   65.5   3.9    55.6   40.1   65.4   59.4   55.9   51.7   49.9
14   77.5   45.0   63.3   3.7    53.9   43.2   66.1   62.0   58.7   54.1   50.7
15   76.3   43.8   57.8   2.6    51.0   36.1   58.6   52.4   51.4   50.8   49.9
16   75.0   43.8   60.0   2.9    52.5   34.2   64.0   58.7   55.3   51.9   50.4
17   81.3   43.8   60.9   3.2    52.7   39.6   63.2   57.0   54.3   52.2   50.9
18   86.3   47.5   70.1   4.4    58.9   51.6   70.8   65.5   62.3   57.4   53.6
19   98.8   45.0   84.5   7.0    66.6   84.9   77.6   72.4   69.6   65.3   60.3
20   92.5   46.3   79.0   5.9    63.9   72.3   75.9   69.4   66.3   62.5   58.6
21   93.8   46.3   86.0   7.2    67.6   92.2   79.5   75.4   73.0   69.0   64.6
22   90.0   46.3   66.6   3.7    57.2   43.5   68.3   62.2   59.2   55.2   52.4
23   65.0   46.3   53.7   1.4    50.1   29.1   55.9   53.8   52.6   51.1   50.1
24   67.5   43.8   52.8   1.6    48.7   28.9   55.6   51.5   50.4   49.7   48.9


HR   L30    L40    L50    L60    L70    L80    L90    L95    L97    L99

 1   47.9   47.5   47.2   46.9   46.6   46.3   45.3   44.6   44.3   43.9
 2   46.1   45.8   45.5   45.3   45.0   44.5   44.1   43.9   43.8   43.0
 3   45.4   45.0   44.5   44.1   43.7   43.3   42.8   42.6   42.5   41.8
 4   45.0   44.8   44.5   44.2   44.0   43.6   42.5   41.9   41.6   41.4
 5   44.1   43.6   43.3   43.0   42.7   42.3   41.7   41.4   41.3   40.7
 6   45.0   44.5   43.9   43.5   43.1   42.8   42.2   41.7   41.5   41.3
 7   48.0   47.4   47.0   46.6   46.2   45.7   45.2   44.6   44.2   43.9
 8   48.7   48.3   47.8   47.4   47.0   46.5   45.9   45.4   45.1   44.4
 9   49.1   48.6   48.2   47.8   47.4   46.9   46.3   45.6   45.3   44.6
10   50.7   52.1   49.7   49.4   49.0   48.7   48.0   47.7   47.6   46.8
11   49.5   49.1   48.7   48.3   48.0   47.6   46.9   46.5   46.3   45.5
12   52.3   51.0   49.9   49.2   48.6   48.2   47.7   47.5   46.9   46.3
13   49.1   48.5   48.0   47.6   46.9   46.2   45.6   45.2   45.1   44.7
14   49.8   49.5   49.1   48.8   48.5   48.1   47.8   47.6   47.6   47.2
15   49.2   48.5   47.6   47.1   46.7   46.3   45.7   45.3   45.2   45.0
16   49.8   49.6   49.3   49.0   48.8   48.3   47.8   47.5   46.8   45.6
17   50.0   49.4   48.8   48.1   47.4   46.9   46.4   45.8   45.5   45.1
18   52.4   51.8   51.2   50.8   50.4   50.0   49.4   49.0   48.9   48.8
19   57.1   54.6   52.7   51.3   50.3   49.5   48.8   48.0   47.6   46.8
20   56.1   54.3   52.9   51.7   50.8   50.0   49.2   48.8   48.4   47.8
21   61.1   58.6   56.5   54.9   53.5   52.3   51.3   50.3   49.8   48.9
22   51.8   51.2   50.8   50.4   50.0   49.5   49.1   48.8   48.7   47.9
23   49.8   49.6   49.4   49.2   49.1   48.9   48.4   47.9   47.8   47.6
24   48.5   48.3   48.0   47.8   47.5   47.0   46.6   46.4   46.3   45.7

              Sample Output Listing
```

A-weighted noise levels were monitored continuously for a full 24-hour period at each site, using portable unmanned monitoring systems we had developed. These systems sampled the noise environment at a rate of 8 times per second. For each sample, the noise signal was A-weighted, converted to a decibel format, and distributed into 1 of 64 bins, each 1.25 dB wide spanning a sound level range from 30 to 110 dB. Once each hour, the contents of the 64 bins as well as the time of day were recorded on a digital tape.

The data tapes were later processed by computer to yield various noise-level statistics and measures for each hour as well as for daytime and nighttime periods. Figures 3 and 4 show a sample output listing for one of the sites. Various statistics describing the cumulative distribution of noise levels occuring for each hour and for the daytime and nighttime periods are tabulated. Also tabulated are the maximum and minimum noise levels, as well as other noise measures, including the equivalent level and the day-night level. Cumulative distribution curves of the daytime and nighttime noise levels are also plotted.



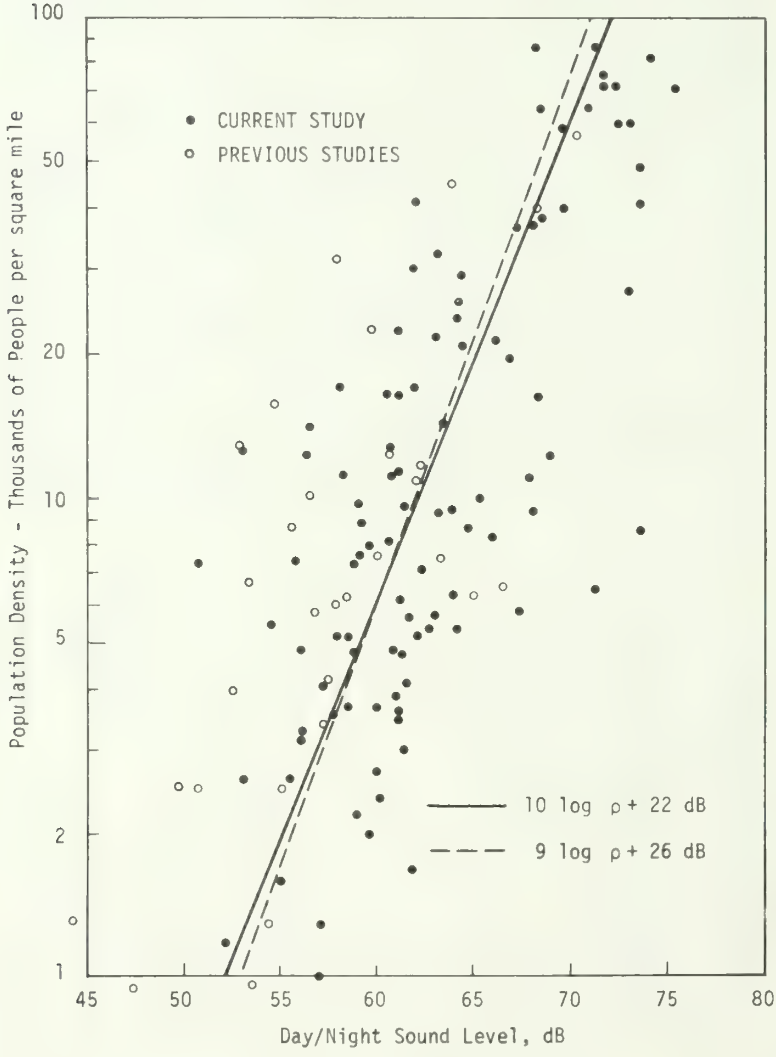
```
            DAY  '.'.    NIGHT  ",".          WEIGHTING    WEIGHTED Leq

MAX         98.8         76.3                     0.           58.7
MIN         42.5         40.0                     8.           59.5
NPL         74.0         56.7                    10.           60.0
SIG          5.2          3.1                    12.           60.7
LEQ         60.6         48.8
TNI         60.4         39.6
L1          71.9         57.6
L3          66.0         52.5
L5          62.7         50.8
L10         57.8         49.6
L20         53.3         48.5
L30         51.4         47.6
L40         50.5         46.7
L50         49.7         46.0
L60         49.2         45.2
L70         48.6         44.5
L80         47.9         43.9
L90         46.9         42.9
L95         46.2         42.4
L97         45.7         41.9
L99         45.2         41.4
```

Sample Output Listing

The day-night levels observed over the 100 sites range from approximately 50 to 75 dB. Figure 5 shows the measured day-night levels plotted vs. the logarithm of the population density. The computed least squares regression line yields an equation showing that L_{dn} is equal to 9 times the logarithm of the population density plus 26 dB. The regression line has a correlation coefficient of 0.72 and a standard error of the estimate of about 4 dB.

If we assume that the noise level varies with 10 times the logarithm of the population density, the model indicates an intercept of 32 for a population density of 10. At the 5-percent level of significance, this regression line with a slope of 10 is statistically insignificant from the least square regression line. Thus, the equation showing L_{dn} equa to 10 log population density plus 22 provides a useful first-order estimate of outdoor levels in urban residential areas in this country.

Figure 5.—Correlation of day-night levels with population density.



Day/Night Sound Level as a Function of Population Density

MODEL APPLICATIONS

If one assumes that at each level of population density, the L_{dn} values are normally distributed about the average level (given by the model equation) with a standard deviation of the same order as the standard error of the regression line (4 dB), one can then estimate the noise exposure for the country, given the population density distribution of the urban population in the United States. This was done, using population-density information for census tracts, obtained from the 1970 census. Some results are given in table I (more detailed results are given in Galloway 1973).

Table I.—Estimated community noise exposure in the United States*

L_{dn} in dB	Number of people exposed to specified L_{dn} or greater
	Millions
55	93.4
60	59.0
65	24.3
70	6.9
75	1.3
80	.1

*Excluding freeway and airport noise.

This analysis indicates that more than 0 million people live in areas with day-ight levels in excess of 55 dB, and 1.3 illion people live in areas with day-ight levels in excess of 75 dB.

The population-density model also rovides a basis for estimating the varition of noise levels throughout a comunity and as a basis for planning etailed community noise surveys. In is approach, noise levels derived from timates of the population density can e viewed as setting a "plateau" noise vel for community areas that are not cated near strong localized noise urces. Then, to this plateau, one can dd the "ridges" and "mountains" conibuted by the noise of strong sources (major highways, railroads, and industrial noise sources as well as aircraft).

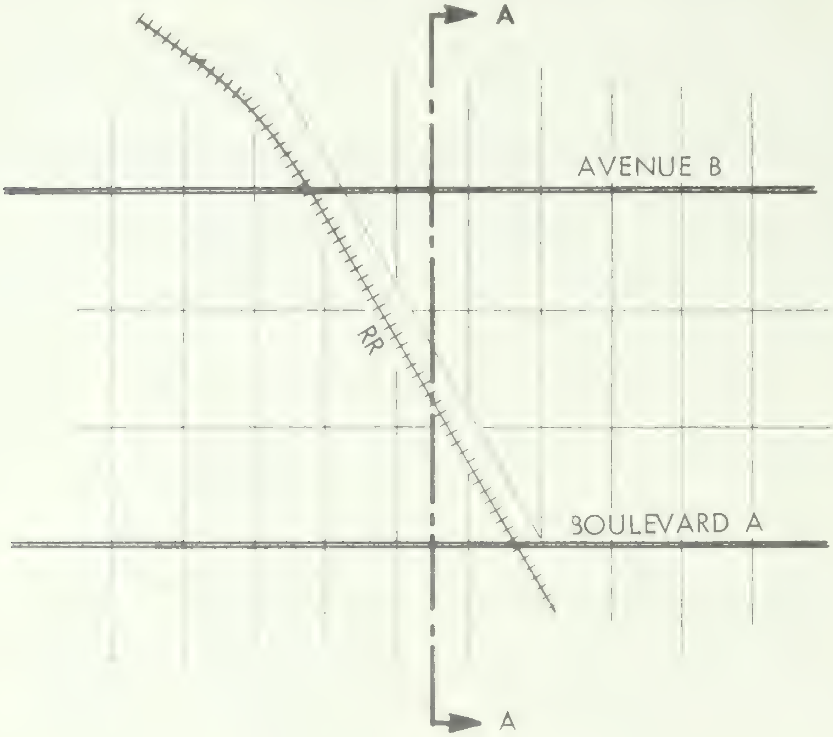
Figure 6 shows this application to a hypothetical community area. The community area of interest is bordered by two major roadways and is intersected by a railroad. The lower portion of the figure shows an estimate of the noise levels throughout Section AA. The plateau noise level given by the population density is shown as is the contribution by the surface traffic sources. This profile may be used to provide first-order estimates of the differing noise exposure through the cross-section. It also provides a basis for initially locating noise-measurement positions for a detailed field-noise survey.

DAILY NOISE-LEVEL TIME PATTERNS

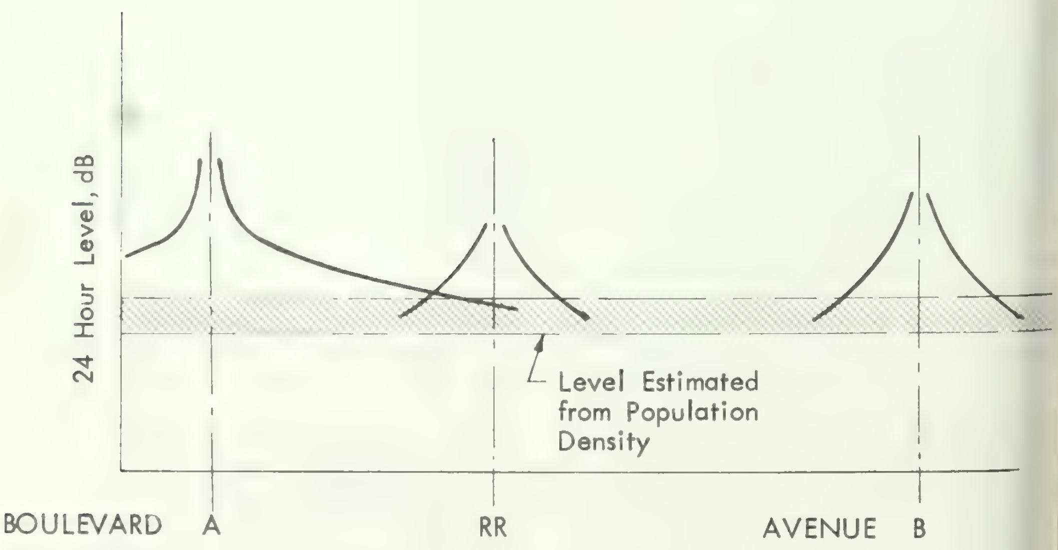
The information collected at the 100 sites throughout the country provided much information in addition to the 24-hour L_{dn} data. The data, for example, provide some insight into the typical variations in noise levels during different times of the day. Figure 7 shows the composite daily noise pattern where the average equivalent level for each hour of the day (across the 100 sites) is plotted as a function of time of day. At each site, the hourly values have been referenced to the day-night level for that site. Thus, the figure shows the difference between the 24-hour day-night average level and the equivalent level for each hour of the day.

Since the difference between the equivalent level at any one hour and the day-night level generally differs from site to site, one can obtain a measure of a variability in relative noise levels with time of day by computing the standard deviation for those differences for each hour of the day. This information may be useful, for example, in determining the best time of day in which to take measurements, i.e. in determining which hourly measures would provide the most reliable estimates of the

Figure 6.—Using the population density model to predict noise-level variations in a community area.

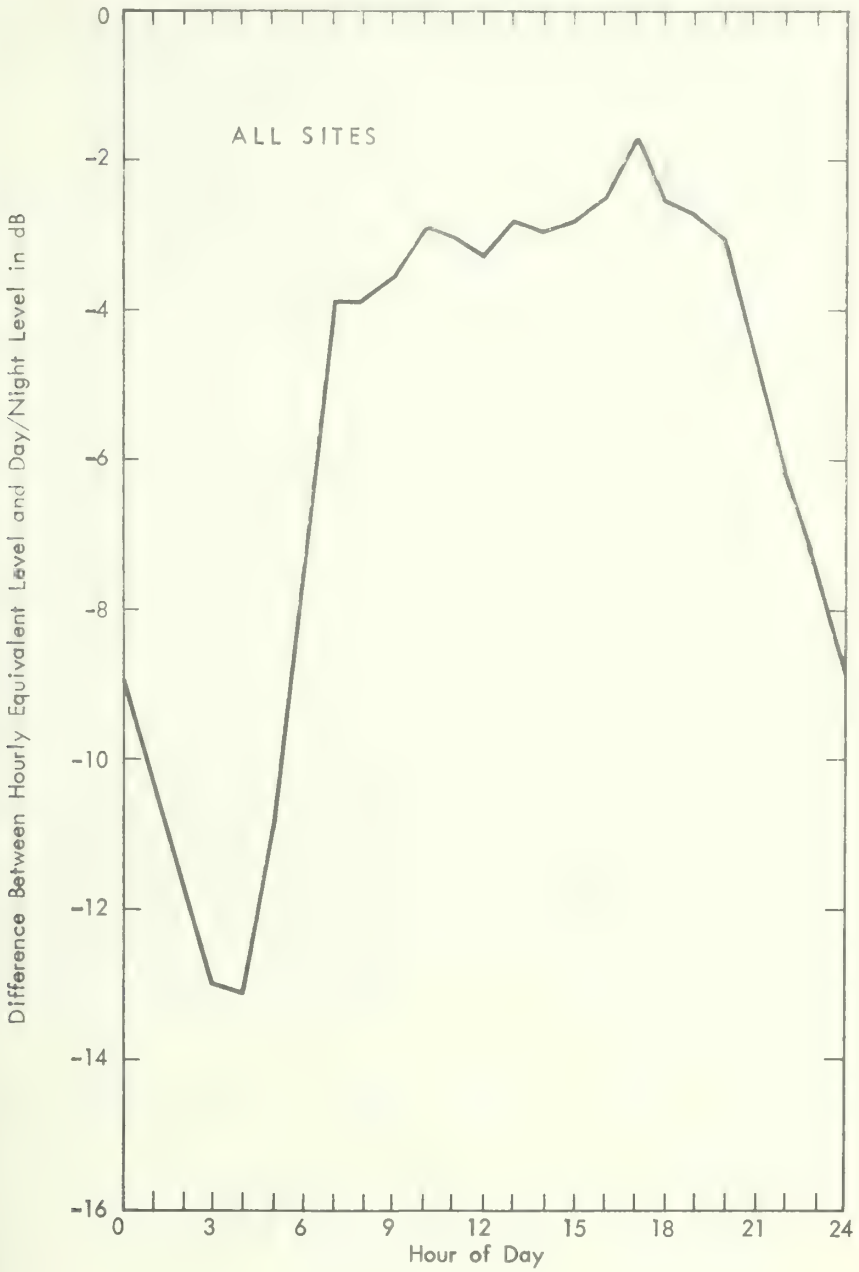


A. MAP OF NOISE SURVEY AREA



B. NOISE LEVEL PROFILE THROUGH SECTION A–A

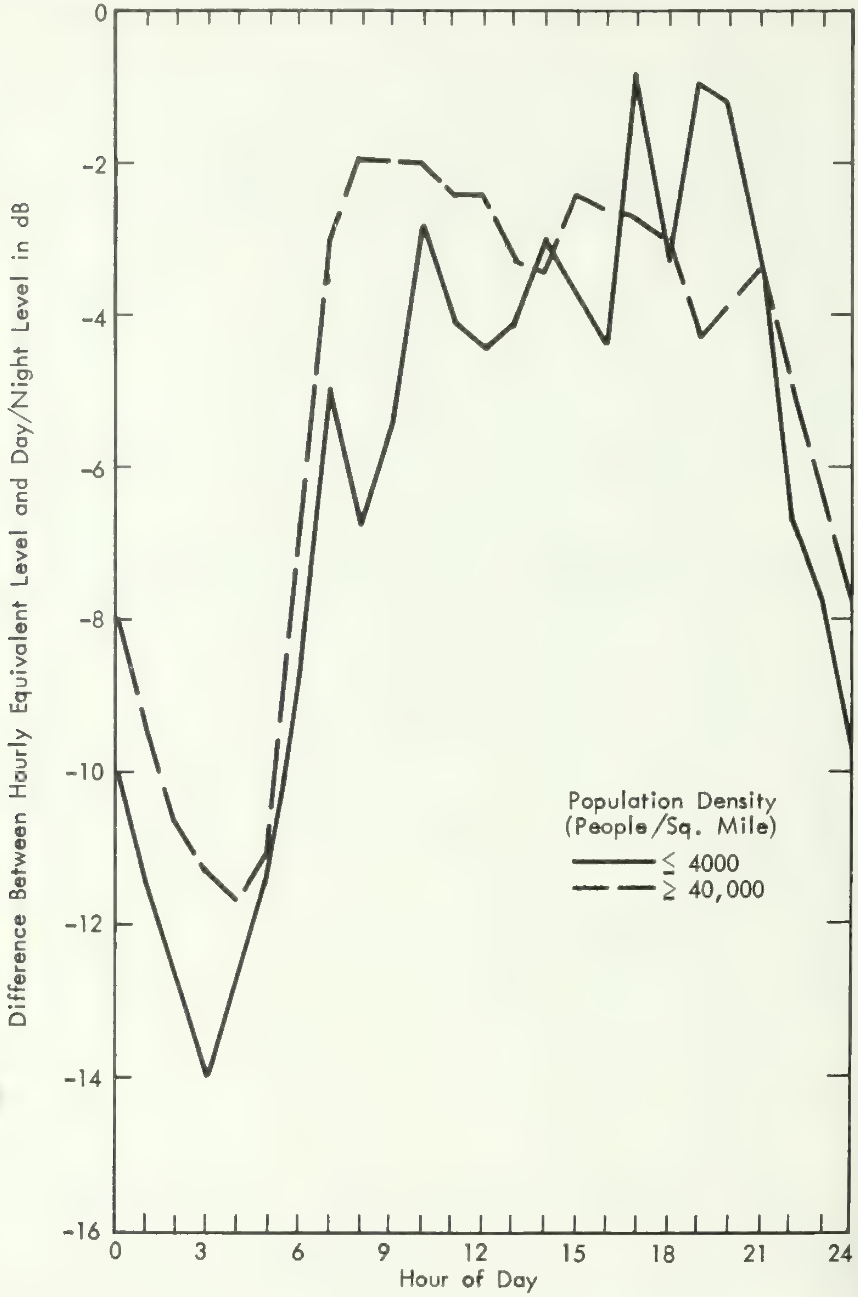
Figure 7.—Average hourly time patterns of noise levels (100-site survey).



2-hour noise exposure. For the data sown in figure 7, the standard deviatns of the hourly averages range from aout 4 dB in the early morning hours, gnerally decreasing through the day t about 2.5 dB in the late evening.

One can examine these daily patterns f sites having different population densities to check if there are differences in patterns for areas having greatly different densities. Some can be anticipated, since the daily traffic flow patterns may differ between high and low density urban areas. As an example, figure 8 shows the variation in hourly noise levels for sites with: (a) popula-

Figure 8.—Hourly time patterns of noise levels for sites of widely different population density.



tion densities of 4,000 persons per square mile or less; and (b) population densities of 40,000 people per square mile or greater.

Several interesting trends can be noted in the comparison. For the lower density sites the range in noise level from minimum nighttime levels to max mum daytime levels is greater—ap proximately 13 dB compared to 10 d for the higher density areas. This con firms earlier measurements showin smaller variations in levels for areas exposed to heavier volumes of daily traffic *(Bishop and Simpson 1973)*.

Another interesting finding is that, in the high-density areas, the noise levels show less variation during the day, with levels reaching a maximum early in the morning and decreasing slightly during the day. In the low-density neighborhoods, more typical of suburban residential areas, the pattern shows a general rise in the noise levels during the day, with a maximum occurring between the hours of 5 and 9 P.M.

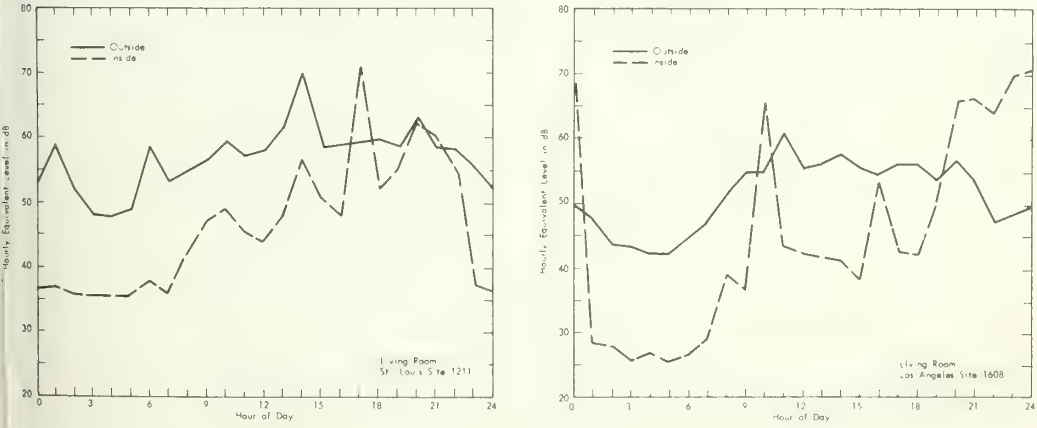
COMPARISON OF INSIDE AND OUTSIDE NOISE LEVELS

Thus far we have concentrated on descriptions of the outdoor noise environment; but most of our time is spent inside buildings, and the noise environment inside a building can bear little relationship to the environment measured outdoors. Thus, it is important to have some knowledge of the correlation of inside and outside noise environments. Sometimes too much importance may be placed on the control of exterior noise if one neglects the noise that is generated by people activity inside a building and the noise resulting from use of appliances, tools, radios, and televisions. Of course, we must remember that much of the noise generated inside a building may be wanted noise and even essential. In contrast, most noise intrusions from the outside are generally undesired.

Typically, in moderately quiet neighborhoods, we would expect the indoor noise environment to be controlled primarily by internally generated noise sources. It is only in relatively noisy outdoor environments that the noise leaking in from the outside contributes measurably to the indoor noise environment. There are extremely wide variations in the noise patterns found in different rooms of a building, depending, obviously, on the degree and kinds of activities.

Figure 9 shows the inside and outside measurements made in two different living rooms. The patterns here show some fairly predictable patterns. In both living rooms, the noise levels during late night hours (from midnight until about 6 or 7 in the morning) fall well below the outdoor noise levels. It is during this night period that exterior noise events most noticeably influence the indoor noise patterns. During the day, both indoor and outdoor noise levels increase, with a marked increase of indoor noise

Figure 9.—Comparison of indoor and outdoor noise levels at two residential sites.



to a maximum during the evening hours when the living room is either occupied or activities are occurring in adjacent areas of the house.

SUMMARY

Field noise measurements consisting of sets of 24-hour measurements made at 100 residential sites scattered across the country confirm a simple model for estimating the community noise environment based on knowledge of the site population density. This model has been used to provide a first-order estimate of the noise exposure in urban areas of this country. The model also can be used in estimating the variation in noise levels in community areas and in planning detailed community noise surveys. Data obtained from the 100-site field study have also yielded considerable information on the time pattern of noise levels occurring during the 24-hour day. Simultaneous inside and outside measurements in residences confirm the general lack of correlation between inside and outside noise levels, which result from the noise generated by people's indoor activities.

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Study of Traffic Noise Levels at Various Heights of a 39-Story Building

by NORMAN L. MEYERSON, *vice president, Ostergaard Associates, Caldwell, N. J.*

ABSTRACT.—Comparative measurements of exterior noise levels made at floors 3, 14, 26, and 37 of a high-rise apartment tower, when presented as a statistical distribution of percent exceedance vs. decibels, show the nature of the influence of local traffic at the low floors compared to the influence of an area source at the high floors. The open window penalty to interior noise levels was measured as well as the side street noise propagation along the building from avenue vehicular traffic sources alone.

THE IMPOSITION OF NOISE-EXPOSURE limits on new urban multiunit living quarters as a prerequisite to acceptability for government financial assistance has encouraged attention to his matter early in the design stage. The U. S. Department of Housing and Urban Development (HUD) criteria end to discourage the construction of ew dwelling units, including the reabilitation of older dwellings, by witholding HUD financial assistance if here are, or are projected to be, unaceptable interior or exterior noise xposures.

HUD Circular 1390.2 specifies exposure standards in terms of categories rmed broadly as; "Unacceptable", Discretionary", and "Acceptable" as easured at appropriate locations along, nd heights above, site boundaries. In ew York City, local interpretation has tended the locations to the facades of e projected or existing buildings beuse most buildings do in fact start at e site line or very close to it. The exrnal noise standards are fundamental realizing an acceptable level of noise in the occupied or dwelling areas of the ilding, with specific emphasis on sleeping quarters. Performance standards limiting interior noise exposure as pulated in Circular 1390.2 are predicated on "open windows unless other ovision is made for adequate ventilation".

The sponsors of high-density housing, such as high-rise apartment buildings, are sensitive to the need to introduce measures to combat noise intrusion. This is particularly so because significant economies are realized when it can be established that, for a particular design, a majority of the living units meet the noise requirements without resorting to costly acoustic measures involving shifts in window exposures, insertion of high transmission loss window assemblies, installation of room or centralized comfort conditioning, etc. Just such a consideration precipitated the request for an evaluation of traffic noise exposure at various elevations on the avenue side of a 39-floor high-rise tower (figs. 1 and 2) and along the avenue side of a flanking L-section wing having 7 floors (figs. 3 and 4). The building is located in midtown Manhattan, fronting on a moderately used north-south avenue and between lightly used cross streets.

Before construction of the building, measurements at the site revealed that the external noise exposure at the avenue side of the tower and at the elevation of the projected lowest residential floor was "Discretionary—Normally Unacceptable" (fig. 5) since the distribution curve passed to the right of the stipulated transition point (X in fig. 5) between being normally unacceptable and normally acceptable. This was

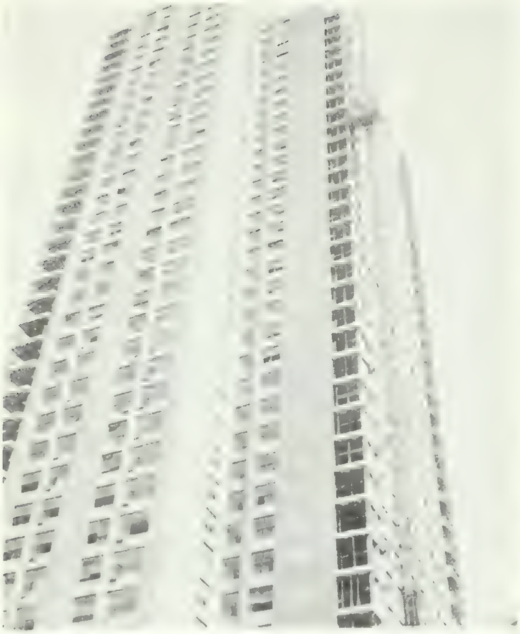


Figure 1.—The 39-floor high-rise tower studied in New York is provided with room air-conditioner openings in the avenue exposure side of the building.

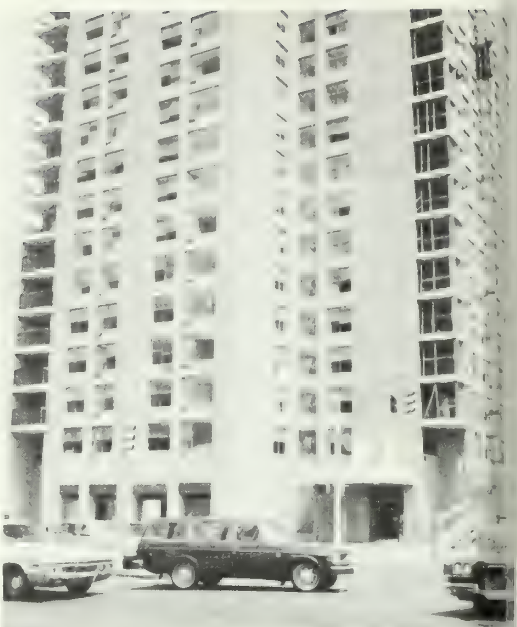


Figure 2.—The entrance and lower levels o
the tower structure.

Figure 3.—The avenue side of the seven-floor L-section wing adjacent to the tower structure.

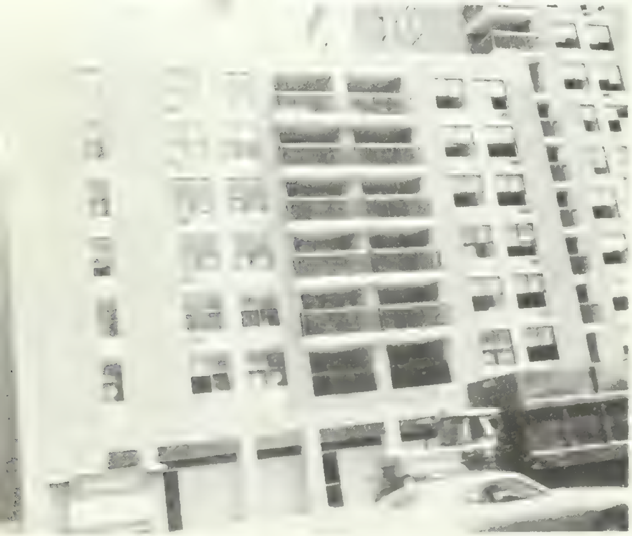


Figure 4.—A side-street view of the seven
floor L-section wing.

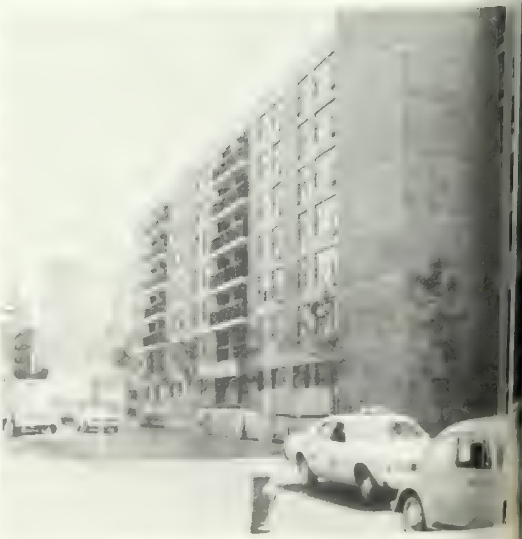
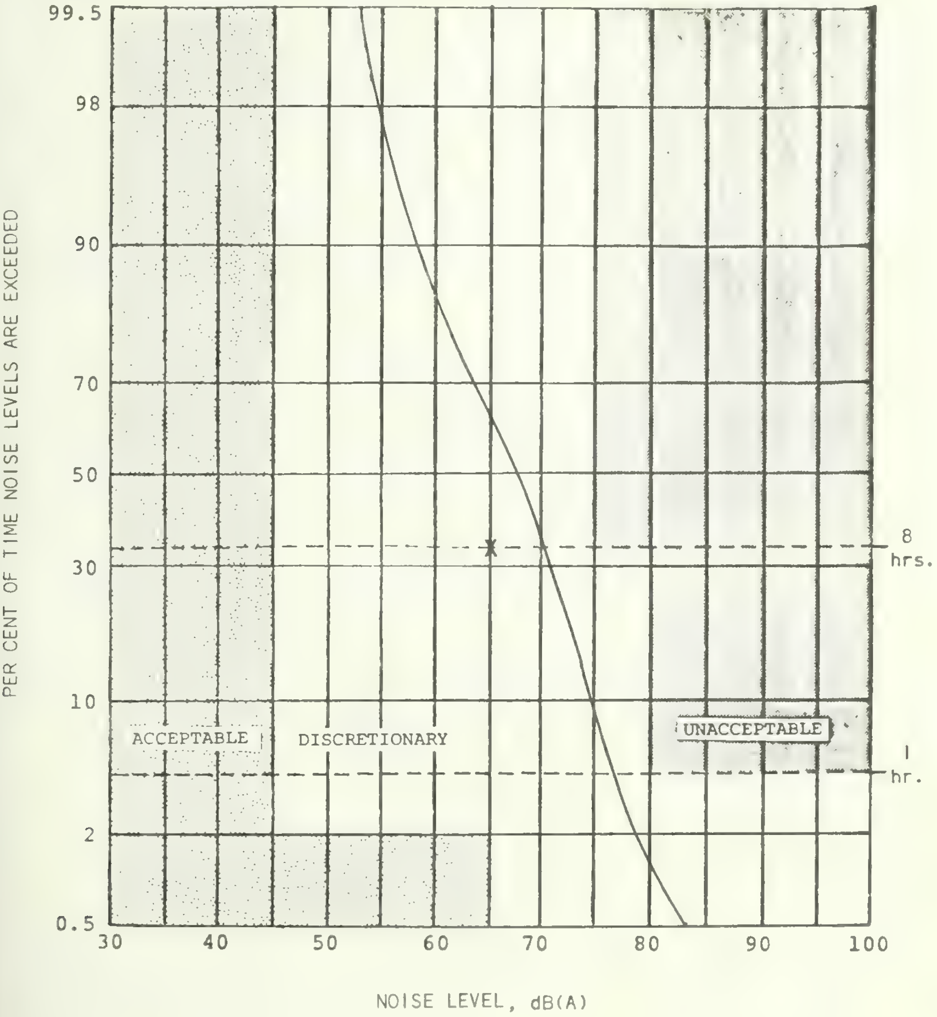


Figure 5.—Statistical exceedance distribution of recorded noise levels over a period of 24 hours at the building site before construction. Traffic in the area at the time of the tests was determined to be mid-week normal with no local street closures or disruptions. HUD Circular 1390.2 exterior criteria has been superimposed. Measurements were taken at the lowest projected bedroom elevation and at the building line.



Based on a 24-hour midweek measurement showing the exterior noise level to exceed 65 dBA for more than 8 hours. Subsequent to this reporting, the building was erected and a repeat test was requested. Because of several important deterrents, the 24-hour test could not be repeated with any degree of reliability. Closing of a hazardous nearby highway caused a redistribution of avenue traffic, and construction activity on nearby streets prompted this decision.

Accepting the premise that the normally unacceptable but discretionary exposure prevailed, and that measures must be taken to assure maintaining interior levels within criteria, a study was sponsored to determine the height at which the external noise standards would meet the discretionary but normally acceptable criteria. All apartments below this level would then be considered for mitigating measures by architectural and mechanical modification.

For exterior measurements at all selected locations, windscreen-fitted microphones attached to booms were extended out from the building facade to a distance of 1 meter and oriented for random incidence. Simultaneous A-weight recordings were made on tape recorders at several levels of the building tower; floors 3, 14, 26, and 37 were selected for approximate equidistance. Since the readings were directly comparable, the level of traffic flow was essentially immaterial; however, to obtain a range of noise levels, testing was started early enough to include rush-hour traffic.

Graphic record comparisons were possible for recordings taken on the 3rd and 14th floors, but the smoother noise variations observed at the 26th and 37th floors made statistical analysis mandatory. Accordingly, analysis samplings of the simultaneously recorded data were

Figure 6.—Statistical exceedance distribution of simultaneously recorded noise levels over a 3-hour sampling period for four tower elevations.

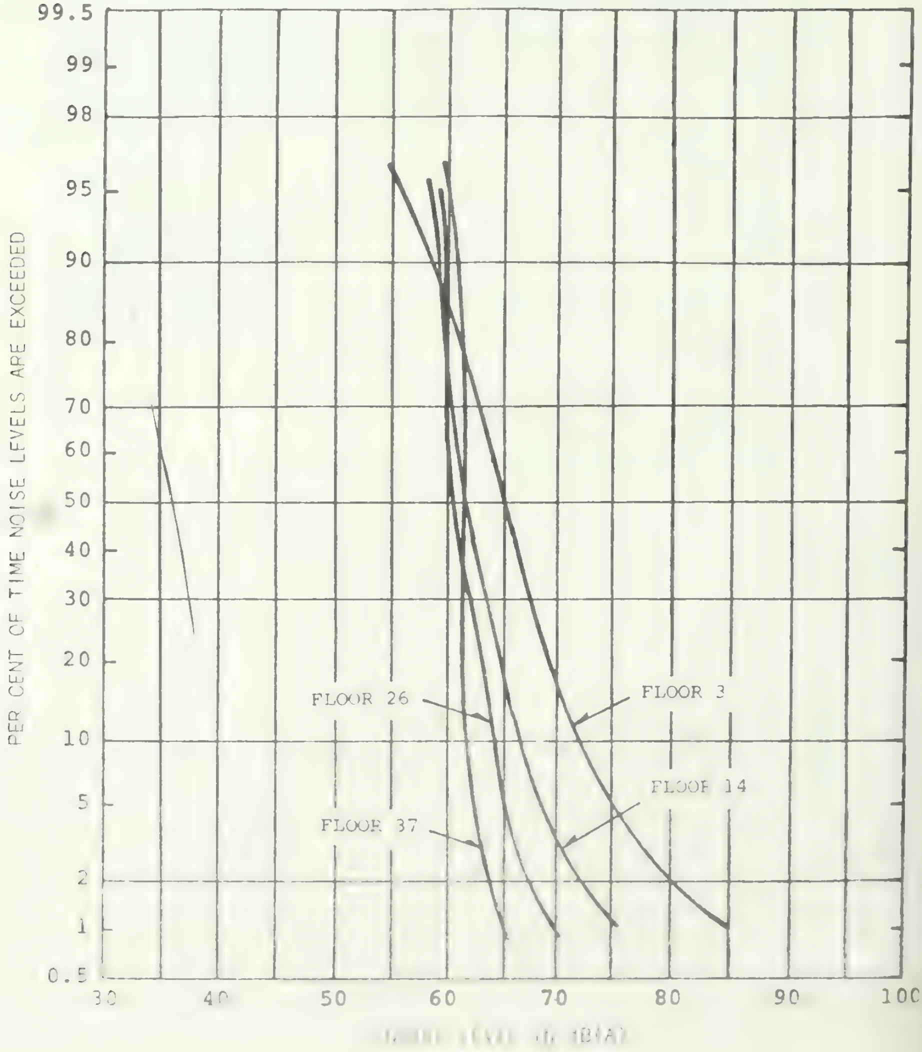
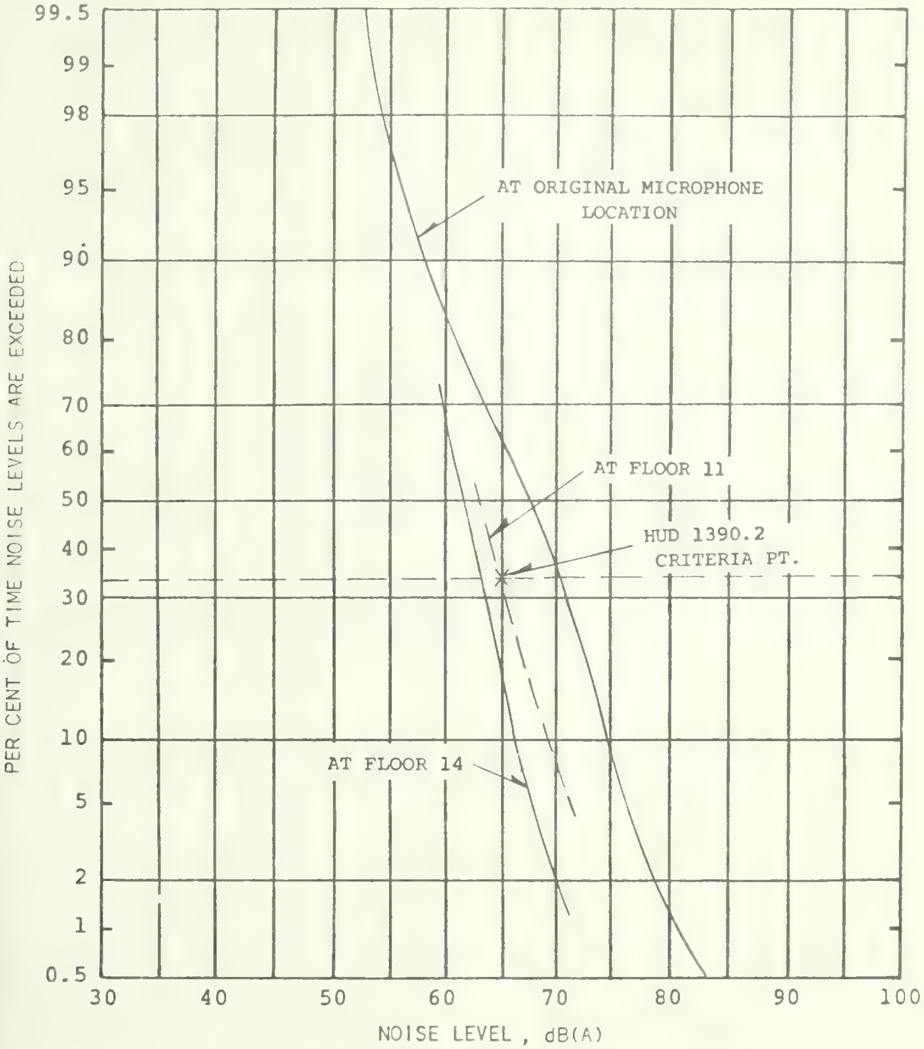


Figure 7.—Interpolation between exceedance curves for the tower floors establishes the approximate floor just meeting the Discretionary-Normally Acceptable criteria.



ken every half-second of the record- g period and accumulated in 5-dB eps (pentads). The results, normalized remove minor variations (fig. 6), owed a distinct convergence of the ceedance curves. For the 37th floor, e curve indicated a relatively uniform ise level approaching an L_{90}, A-weight, sidual value of approximately 61 dBA. floor 3, the full impact of local enue traffic was experienced, with der excursions of noise level. The intermediate floors, 14 and 26, indicated a relatively lower influence of immediately local traffic noise.

Transposition of the elevation adjustment to the original normal traffic noise base permitted an interpolation approximating the tower floor that would have an exceedance curve (fig. 7) to the right of the discretionary transition point. This was computed to be floor 11. Mitigating measures were indicated as recommended for residential floors 2 through 11 on the avenue side of the tower and all six residential floors of the avenue side of the building wing.

Sutherland *(1975)* has reported a recorded A-weight residual level ranging from 69 dBA to 73 dBA from ground level to 20 floors above ground level at another high-rise apartment site in New York City. For the particular study made by Sutherland, his L_{90} residual levels were materially higher than those recorded during this investigation since the nature of the local and distributed sources of noise were different. However, a similar flat L_{90} relationship was found when the L_{90} A-weight levels were plotted as a function of the various floor heights above ground.

An additional series of tests were performed at each of the test floors. A bedroom window on each test floor was opened so that the open area was 5 percent of the floor area of the room, essentially complying with the New York City building code minimum requirement for adequate ventilation. Microphones were set up in the center of the rooms and directly outside on the 1-meter booms. In each case, when the window was open, the room level was 12 dBA greater than when it was shut. The windows were conventional Alwinseal double hung sash with DSB (1/8-inch) glass.

On the side street, along the L-wing of the building, the effect of avenue noise was determined by locating microphones exterior to rooms e, f, and g (fig. 8) located on the 5th floor of the wing. Simultaneous recordings were made only during intervals when no traffic moved on the side street and with active traffic motion on the avenue. The noise level distribution at the test locations in terms of statistically accumulated pentad samples (fig. 9) shows a con-

Figure 8.—Section view through tower and L-wing showing apartment and room locations and the designation of measurement rooms (a, b, c, d, e, f, g).

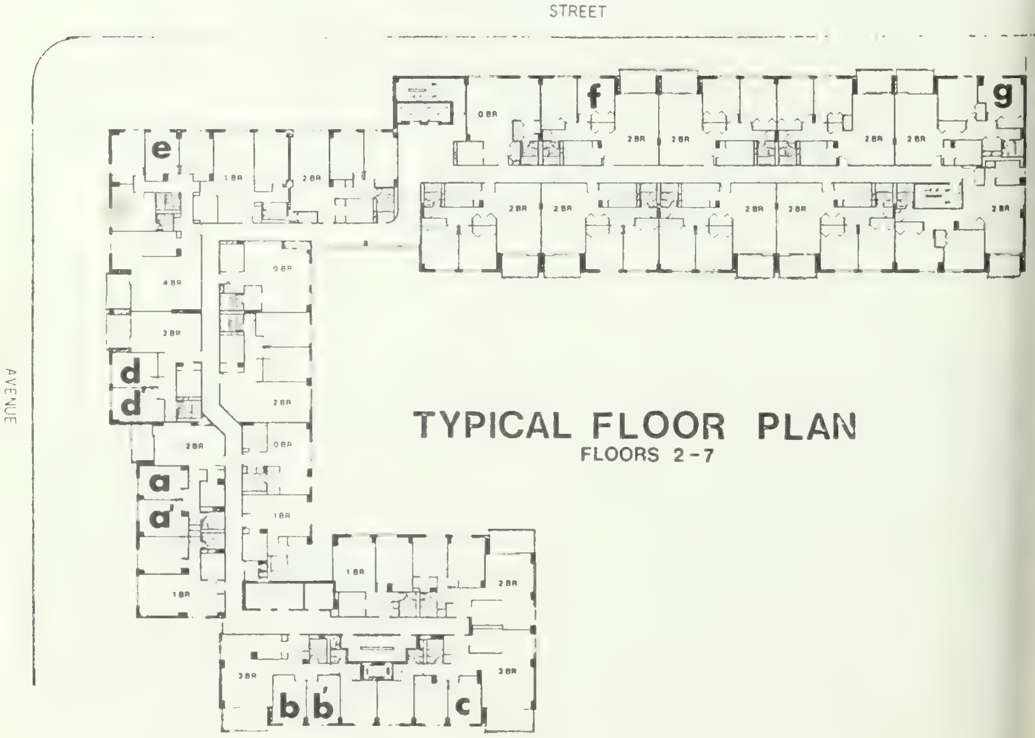
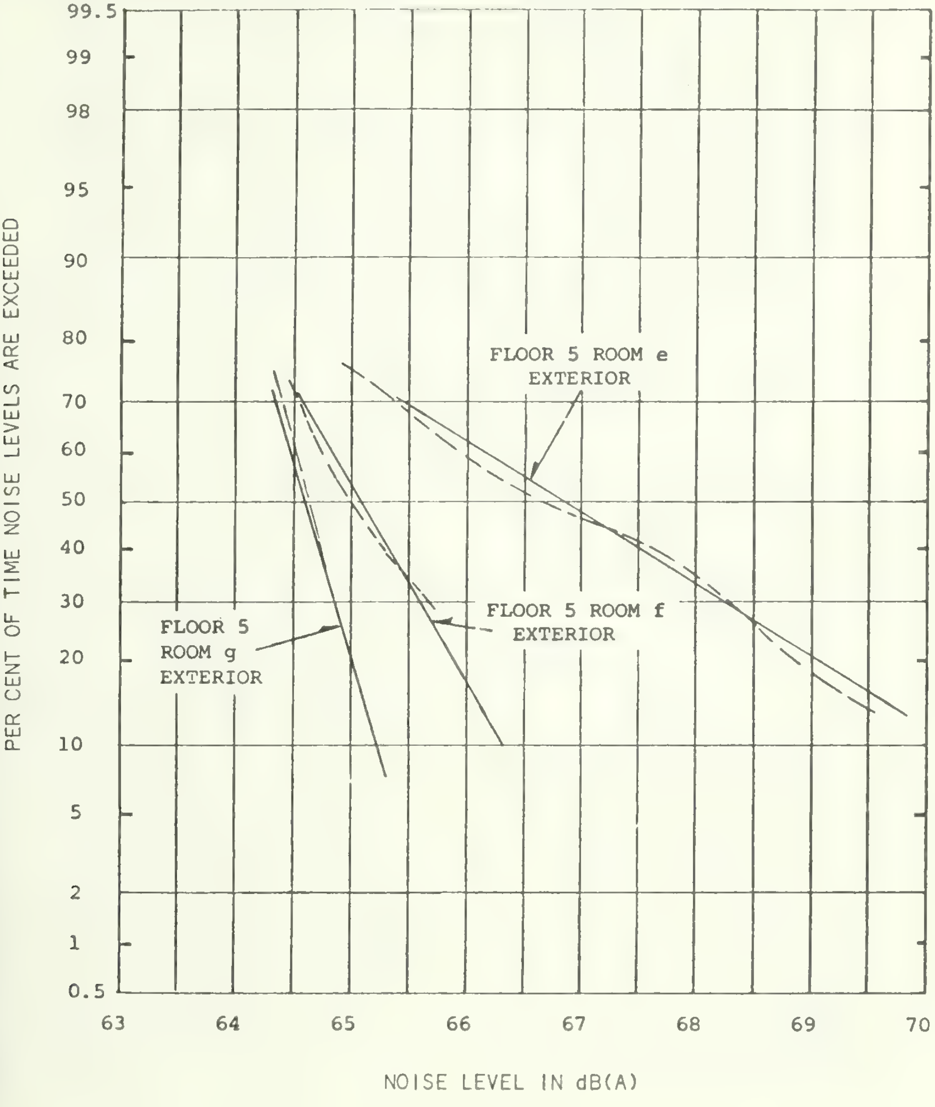


Figure 9.—Statistical exceedance distribution of recorded exterior noise levels along the street side of the L-wing at three widely separated locations. Noise is primarily from avenue traffic, with no moving traffic on fronting street.



rging pattern, the remote location exbiting the lowest and smoothest aracteristic.

Much work remains to define in depth e effect of vehicular traffic noise on gh-rise structures with respect to local d distributed sources as an aid for anning and architectural design.

LITERATURE REFERENCE

Sutherland, Louis C.
1975. Ambient noise level above plane with continuous distribution of random sources. J. Acoust. Soc. Am. 57 (6, part II) : 1540-1542.

Community Noise Monitoring Program

by ARNOLD G. KONHEIM, *Office of Noise Abatement and Control, U. S. Environmental Protection Agency, Washington, D. C.*

ABSTRACT.—There are numerous questions in regard to methods, instrumentation, and human and agency resources for community noise monitoring. The U. S. Environmental Protection Agency is currently in the process of seeking answers to these questions through research within the agency and by cooperation with other organizations, including the Department of Defense and the National Bureau of Standards. EPA hopes to have an acceptable protocol for community noise monitoring by July 1977, but there will still exist a long-term requirement for developing more meaningful and efficient techniques.

LISTENING TO MY COLLEAGUES who preceded me, one might infer that environmental noise monitoring is such a well-explored field that its challenges lie only within deep acoustic crevices. I am sure that they would be the first to admit that this is not the case.

At EPA, we are asking some basic questions concerning noise monitoring, and it is to this phase of our activity that my remarks are addressed. It is hoped that the considerations raised here will contribute to this conference in the following manner:

1. By familiarizing you with the problems of community noise-monitoring.
2. By encouraging greater participation in the search for solutions to these problems.

WHY MONITOR?

EPA is currently in the midst of developing an environmental noise-monitoring and assessment program to satisfy the following needs:

1. Develop an environmental noise baseline to asses future trends.
2. Identify populations at risk in terms of public health and welfare from the standpoint of exposure to noise sources and mixes.
3. Establish standard methods to assure quality assurance in the area of data collection and processing.
4. Provide technical assistance to state and local governments in the characterization of their environments.
5. Collect noise data to support EPA's standards and regulatory activities.

To meet these needs we are in the process of developing a protocol to answer three basic questions:

1. How shall we monitor (i.e., what is our methodology)?
2. What are our instrumentation requirements?
3. What are our resource requirements?

We are committed to seeking answers to all three questions. However, as this program is only in its initial stages, emphasis has been placed on solving the first two questions.

APPROACH

One can categorize monitoring in several ways. A first breakdown might be to separate an assessment based upon the physical collection of data from that based upon a social or attitudinal approach. Monitoring can also be looked at in terms of focus. Are we seeking to obtain an integrated community measurement, merely examine specific sources, or determine the exposure experienced by persons of different life-style's throughout their daily activities?

Based upon the above, it appears that one can investigate six combinations of monitoring approaches; in fact, these reduce to three. All of the social techniques are based upon interviews with community residents: only the questions vary. Physical personal monitoring is effected by instrumenting an individual with a personal noise-exposure meter or dosimeter which he wears for a particular period. The other physical techniques, i.e. integrated community and source specific, consist of instrumenting the community. While we are approaching monitoring from all of these directions, I will direct my remarks only to the physical integrated community and physical source-specific measurements.

SPECIFIC AREAS OF INVESTIGATION

The first area of investigation is the methodology for data collection. We are seeking to find solutions to the following uestions:

How shall we temporally sample?

How shall we spatially sample?

To what extent and in what way is noise source identification important?

What must our monitoring system performance characteristics be?

To what extent do indoor and outdoor measurements correlate?

As part of a trend evidenced by instrumentation in general, noise-monitoring systems process data through a digital processing network. Digitization implies a sampling rate. Thus, our first concern, within the temporal domain, is determining a minimum sampling rate, for example 100 samples/s, 1 sample/s, or 0.1 sample/s. Looking at longer time periods, what should be our minimum daily sample (1 hour/day)? How do we treat cyclic and seasonal patterns?

Within the spatial domain, areas of concern are as follows;

1. By what techniques shall we sample (deterministic, stratified)?
2. What criteria shall be used for site selection?
3. How many sites must be selected for a particular criterion?
4. What are the effects of sampling at various heights?

In noise-source identification, what are the problems attendant to and the advantages of identifying sources through human observers, through microsampling, and through signal processing? What are the important output parameters (L_{eq}, L_{dn})? How do we relate indoor to outdoor measurements?

Another methodological area of concern is the processing and assessment of data. Just where is data to be processed and by what means? How can the data best be assessed to accomplish our program objectives, and how can it best be presented so that it is most meaningful to those people who must make decisions?

Our concerns with instrumentation are both systems- and component-oriented. With regards to the system, we are concerned with both its technical capabilities and its ability to perform under field conditions. Thus, we are concerned with such factors as security, weather, ability to withstand vibration, and operating at long periods of time without inspections. We are also concerned with components. What microphone system is suitable for use at long periods of time in the outdoor environment? What kind of windscreen shall be used with this? How can tape mechanisms and computers function in the outdoor environment?

We are concerned with obtaining nonacoustic as well as acoustic information. Nonacoustic data which may be useful are windspeed, temperature, humidity, source to microphone distances, and speeds of transportation sources. Although most monitoring approaches collect and perhaps even partially process information at the site, it is possible to telemeter the information back to a central location. Is telemetry a viable approach; and if so, to what extent is it useful?

IMPLEMENTATION

Our basic philosophy in answering some of the questions that have been raised today has been to consider each of the areas separately with the intention of integrating these as we find solutions applicable to the various areas. To the maximum extent possible, we have limited our own research by applying the results gathered by other investigators. Using EPA regional and headquarters resources, we have field-tested methodologies and instrumentation systems while collecting data valuable to our agency as well as local communities. Our community monitoring has included cities ranging in size from Morgantown, W. Va, to New York City. In the area of monitoring source-specific areas, we investigated the noise associated with railroad yards and along rights-of-way. Presently, we are planning a construction-site monitoring program in which we will study all types and phases of construction activity.

Now let us review some of our approaches to obtaining solutions to these problem areas.

Most of the temporal analysis has been accomplished or is being accomplished through the multiple processing of analog tapes. In October 1974, utilizing our regional resources, we collected over 1,800 hours of digital data during the previously mentioned railroad monitoring. In addition, we gathered approximately 20 hours of analog recordings. We are now processing a selected group of these analog tapes to help us arrive at a proper temporal sampling plan. First, we are interested in determining the effect of various response times on sampling accuracy. Second, we are investigating the accuracy in deriving selected hourly statistics (for example, L_{eq}, L_1) for a range of sampling rates for 45-minute tap segments. Starting with the highes sampling rate (approximately 20 Hz) the rate will be lowered until the level differ from the original baseline rate o approximately 5 dB. In order to determine the necessity for continuous monitoring, hourly statistics obtained i 5-minute intervals will be compare with that for the entire tape length. A study will be conducted on the effect o changing that point on the tape at whic the sampling starts. Finally, the hourl statistics will be determined by usin the linear A, C, and D weighting networks for railroad yard noise and train pass noise to determine the extent t which low-frequency energy contribute to community noise.

Determining the optimal way t sample spatially appears to be a muc more difficult problem. Two years ag when we initiated the noise-monitorin program, we brought to EPA a panel o experts in noise monitoring for a one day session where we discussed wha constituted good monitoring procedure The area in which we found the leas agreement among those experts was o the approach to spatial sampling. Moreover, in fall 1974, at the meeting of th Acoustical Society of America, we presented a paper on spatial sampling. Th first part of the investigation was dedicated to a review of previous community noise surveys. We studied thes surveys with respect to the followin criteria:

1. Number of sampling stages.
2. Sampling technique applied by stage
3. Spatial criteria used by stage.
4. Total sampling area.
5. Survey length.
6. Total number of measurement site
7. Length of measurements made pe site.
8. Number of equipment systems an the survey objectives.

We found that there were nearly a many sampling procedures employed a there have been studies performed. Ow ing to the variability in objectives and other parameters of community noise surveys, it appears that no single sampling procedure is optimal for all community noise surveys. There is a need for a statistical analysis of the relationships of the various proposed spatial riteria to sound descriptors. What we re asking is: which criteria are necessary for characterizing spatial changes n community noise?

We are about to begin an analysis of reviously collected data to answer this uestion. It is intended through applica- ion of our regional resources that we an further determine the number of ites per criterion by implementing a rogram of multiple site monitoring. n the area of three dimensional sampl- ng — i.e., looking at height variations – we have just completed a noise sur- ey at the Crystal City area of Arling- on, Va., in which we located monitors bove the top of an 11-story building nd in various locations on the ground determine if we can integrate spa- ally by measuring from above the area. addition, our regional office in Den- r, Colo., has been investigating aerial oise sampling from a balloon suspended pproximately 1,300 feet above Boulder, olo.

Until now, we have hired college stu- nts to act as observers so that we ight have a record of what noise urces predominated during a monitor- ig interval. We are, however, look- ig at other approaches to noise-source ientification. We recently purchased icrosampling systems to operate in cnjunction with our all digital noise- nitoring systems so that we might be ale (through time compression) to de- re noise-source identification informa- tin. Recently we initiated programs to tt feasibility of signal processing as a echanism for noise-source identifica- tin. We are looking at techniques such as cross-correlation, which have been ud to distinguish among various noise- srce generators. Most of the technology for this was developed by the Department of Defense. We are now asking the question: can this technology be transferred at a reasonable cost?

Presently, the U. S. Army's Construction Engineering Research Laboratory is evaluating noise-monitoring systems for us in the field and in the laboratory. We expect the results to be completed within the next month.

The National Bureau of Standards is currently investigating various microphones for application to outdoor noise monitoring. These include condenser, electret, and ceramic microphones, which are being evaluated as a function of temperature (−20° to +50°C) humidity (25 to 95 percent) and frequency (100 to 5,000 Hz). The actual acoustics tests have been completed. NBS will now perform a cost analysis before preparing a final report. In cooperation with the Navy, we are studying the application of telemetry to environmental noise monitoring. Low-cost telemetry and sensor units developed by the Department of Defense show great promise, particularly for systems in which only limited information is brought (e.g., threshold detection).

Another concern is, where shall we process data? We intend to tackle this through an operations-research study scheduled to begin this fall, after which we will concentrate on data assessment and data presentation.

CONCLUSION

While we hope to have answered many of these questions to the point that an acceptable protocol will have evolved by July 1976, there is a long-term requirement for developing more meaningful and more cost-effective techniques.

The multitude of problems we face requires the skills of many disciplines: scientists, engineers, environmentalists, urban planners, social scientists, and statisticians. It is an exciting field. I encourage your participation.

Sound Absorption Characteristics of Tree Bark and Forest Floor

by G. REETHOF, O. H. McDANIEL, *and* G. M. HEISLER, *respectively professor and research assistant, Noise Control Laboratory, The Pennsylvania State University, University Park, Pa.; and research forest meteorologist, USDA Forest Service, Northeastern Forest Experiment Station, Pennington, N. J. This research was supported by funds provided by the Northeastern Forest Experiment Station through the Pinchot Institute for Environmental Forestry Research, Consortium for Environmental Forestry Studies.*

ABSTRACT.—Results of basic research on absorption of sound by tree bark and forest floors are presented. Amount of sound absorption by tree bark was determined by laboratory experiments with bark samples in a standing-wave tube. A modified portable standing-wave tube was used to measure absorption of sound by forest floors with different moisture contents, with and without leaf litter, and with and without moss growth. The implications of the results are discussed in terms of the amount and mechanisms of sound absorption by entire forests.

PLANTINGS OF TREES and shrubs of sufficient density and depth are well known to reduce some highway and industrial noise. The pioneering work of Eyring *(1946)* and subsequent work by Wiener and Keast *(1959)*, Embleton *(1963)*, Aylor *(1972)*, Cook and Van Haverbeke *(1971)*, and Reethof *(1972)* generally showed that attenuation of noise by forests depends on four factors:

1. Forest density.
2. Forest depth.
3. Frequency of noise radiated by the source.
4. Micrometeorological factors such as temperature gradients and to some extent wind velocity and vertical wind profile (wind is significant only if large distances between source and receiver exist).

The attenuation of noise by forests is usually expressed by the terrain loss coefficient, which is the acoustic transmission loss between any two specified points, x_2 and x_1, in the forest corrected for spherical divergence and divided by the distance $x_2 - x_1$. The terrain loss coefficient is, therefore, the transmission loss per unit of forest depth.

The results obtained by several investigators are given in figure 1, whic is a plot of terrain loss as a function source octave band frequency. The r search was done in natural forests typ cal of the northeastern United State which contained considerable rhodode dron or mountain laurel in the unde story. The important fact is the lo absorption at frequencies up to abou 500 Hz, with marked increases in ab sorption with increasing frequenc above 500 Hz. Typical truck and auto mobile noise spectra are fairly flat, wit peaks in the 125-Hz octave band (fi 2). We conclude, therefore, that severa hundred feet of forest are required t provide significant reductions in the A weighted sound levels from vehicula traffic.

The mechanisms of noise propagatio and attenuation in forests is comple Consider a sound wave of, for exampl 1000 Hz frequency (with a wavelengt of about 1 foot) entering a forest. Th tree trunks with diameters comparabl to the wavelength will partially refle and slightly refract the incident wav This process is called scattering. Th low-frequency waves (wavelength larg compared to trunks and branches) wi

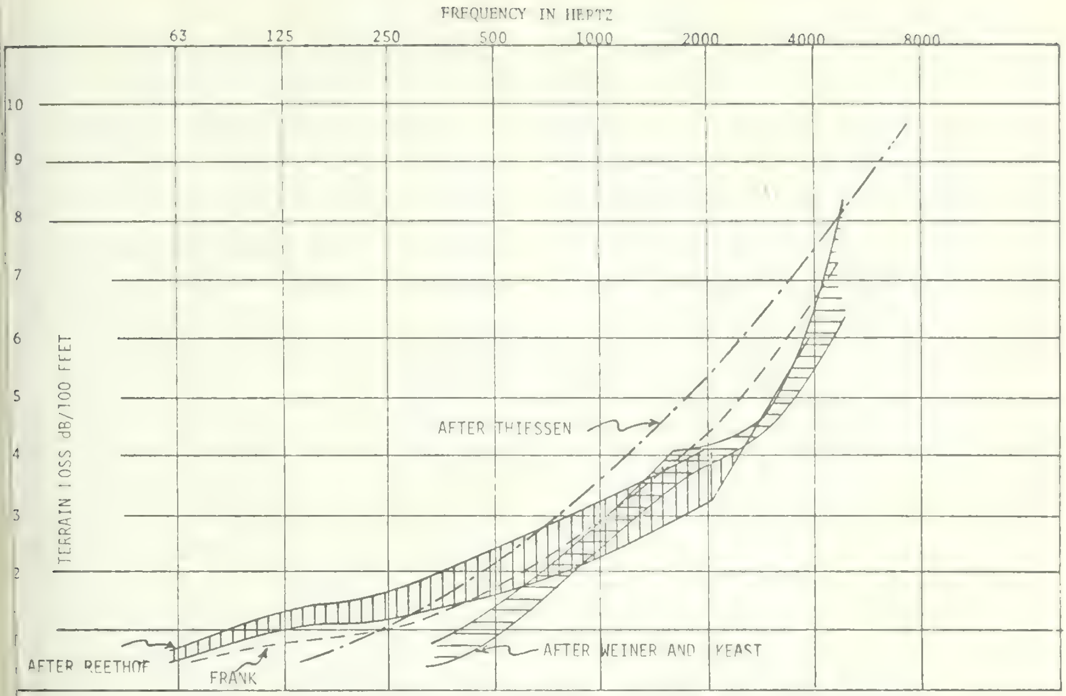
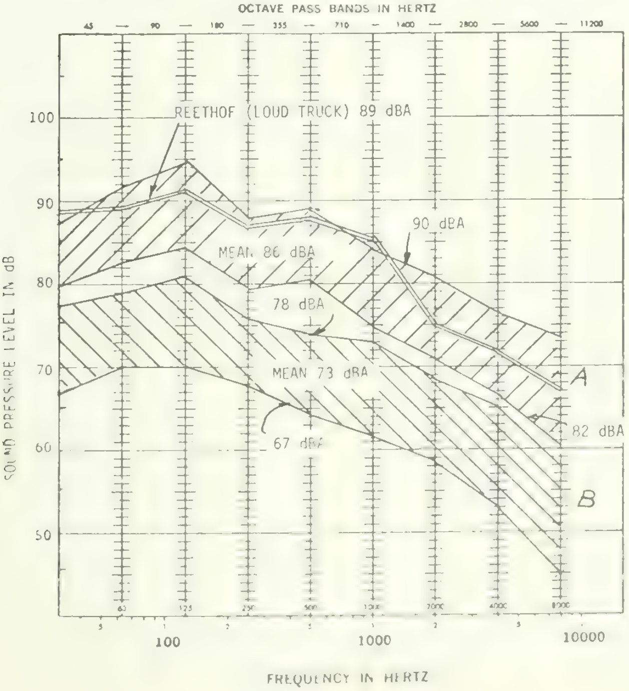


Figure 1.—Terrain loss of typical forests in northeastern United States and eastern Canada as a function of noise frequency *(Frank 1971 and Thiessen 1969)*.

Figure 2.—Octave-band spectra for vehicular traffic.



A--Tr[illegible]

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be transmitted almost unaffected by this phenomenon, whereas the high frequencies (> 1000 Hz) will be increasingly scattered with increasing frequency. This means that, with increasing frequency, the transmission paths will become increasingly complex and longer, providing greater opportunities for acoustic energy absorption to take place. Aylor *(1972)* has shown theoretically and experimentally that canopies, branches, and stems should be expected to provide some acoustic energy absorption as a result of viscous damping and thermal excitation. This phenomenon should be effective primarily at high frequencies.

At maturity, trees such as white oak *(Quercus alba)*, black gum *(Nyssa sylvatica)*, eastern hemlock *(Tsuga canadensis)*, and eastern white pine *(Pinus strobus)* have thick layered bark with considerable porosity. The possibility of absorption of substantial acoustic energy by bark in the multiple--scattering process should, therefore, be explored. In this paper we report some results of a study of normal incidence absorption by tree bark.

The effect of the ground is twofold. First, there is acoustic interference between the ground-reflected wave and the direct wave from a coherent source some distance above the ground. This "cancellation" is caused by the fact that the ground-reflected wave has to travel a longer distance than the direct wave, so that there will be a location at a certain distance from the source where the two waves are exactly at opposite phases, thus bucking one another. Acousticians will also recognize that because of the porosity of the ground, the reflected wave, as it leaves the ground, will be at a somewhat different phase than the incident wave at the ground surface.

The second effect of the forest floor is that it is a good absorber of sound because of its porosity. Typical forest-floor surfaces contain much decayed plant matter such as leaves, needles, branches, decayed trunks, and loose soil. Aylor *(1972)* performed grazing-incidence tests on open fields of unplowed, plowed, and disked soils. An excess attenuation of 6 dB per doubling of distance was shown to be possible. To study forest-floor absorption characteristics under more closely controlled acoustic conditions, we performed normal-incidence absorption tests, which will be reported here.

In all, the acoustics of forests are complex in that several forest elements affect the propagation processes in different and interacting ways. A study of the acoustic characteristics of the individual elements of the forest such as bark, canopies, shrubs, and forest floor should provide needed insight into the acoustic absorption mechanisms. Such insight will then permit the cultivation of the most important elements to maximize acoustic absorption.

BARK AS A SOUND ABSORBER IN FORESTS

Normal (perpendicular) incidence absorption of tree bark was measured with a standard impedance tube, also known as a standing-wave tube, manufactured by Brüel & Kjaer Instruments, Inc. Cylindrical test samples were cut from slabs of tree boles, leaving the wood intact behind the bark. Six species were tested: northern red oak *(Quercus rubra)*, mockernut hickory *(Carya tomentosa)*, eastern white pine, American beech *(Fagus grandifolia)*, eastern hemlock, and a cork oak *(Quercus suber)*.

The standing-wave tube is used to determine the fraction of the incident acoustic energy absorbed by a material in order to compare the effectiveness of various materials as acoustic absorbers The apparatus generates pure tone waves that travel down the tube and strike the sample. Part of the acoustic energy is absorbed within the material then the remaining energy is reflected and travels back up the tube. The super position of the incident wave and the reflected wave establish a standing wave, which occurs as a result of the interaction of two waves of the same frequency traveling in opposite directions. The amplitude maxima and minima, measured from the standing wave, are used to calculate the absorption coefficient. A typical axial pressure pattern s shown in figure 3.

Figure 4 shows a schematic diagram f the apparatus. The sample holder is mounted at one end of the 10-cm diameter, 1-meter long impedance tube. A loudspeaker is mounted in a box at the other end of the tube. A frequency oscillator produces selected tones, and a frequency counter monitors the tone sent to the speaker to insure accuracy within ± 1 Hz. During operation, a 1/8-inch diameter microphone probe tube is moved longitudinally and centrally into the impedance tube. The microphone, located in the movable carriage, monitors the magnitude of the sound pressure of the standing wave. The signal from the microphone goes through a preamplifier to an audio frequency spectrometer. The absorption coefficient is then read from a calibrated scale on the

Figure 3.—A typical axial pressure pattern of the standing wave in the impedance tube.

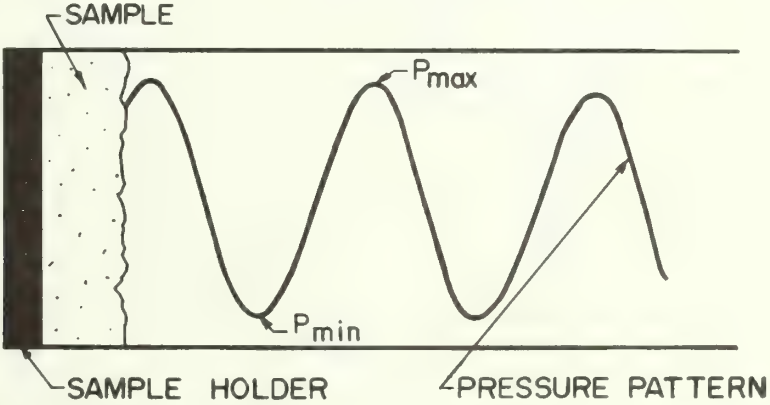


Figure 4.—Schematic diagram of the impedance tube apparatus.

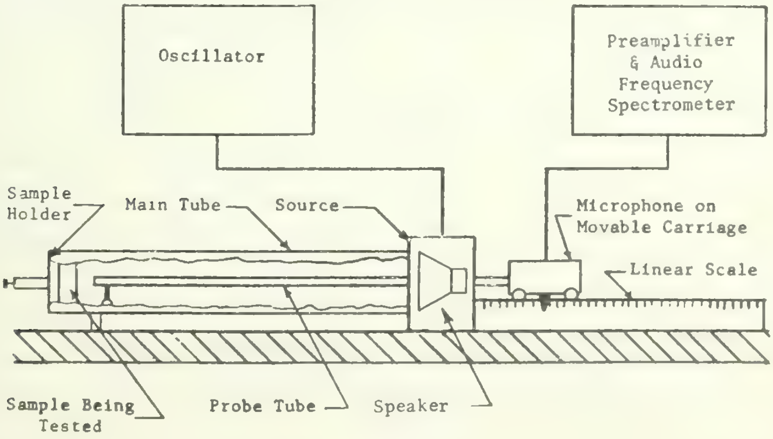


Figure 5.—Absorption of normal-incidence sound by bark of northern red oak.

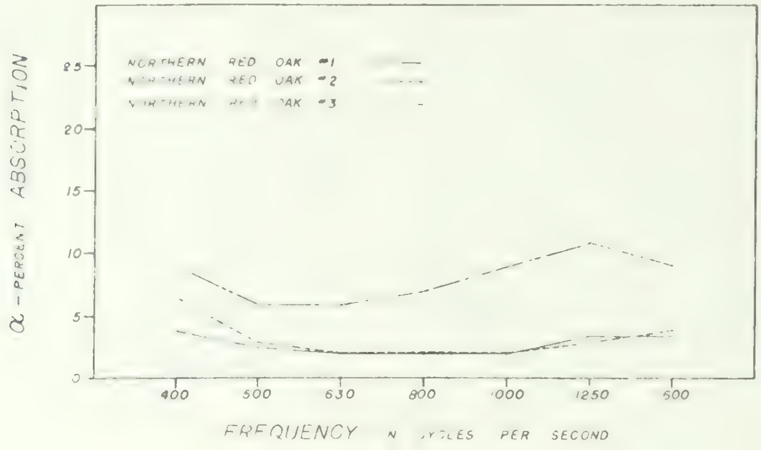


Figure 6.—Absorption of normal-incidence sound by bark of mockernut hickory.

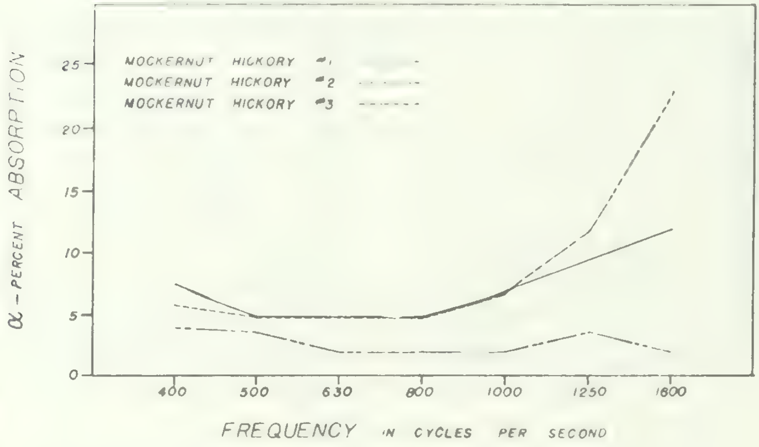
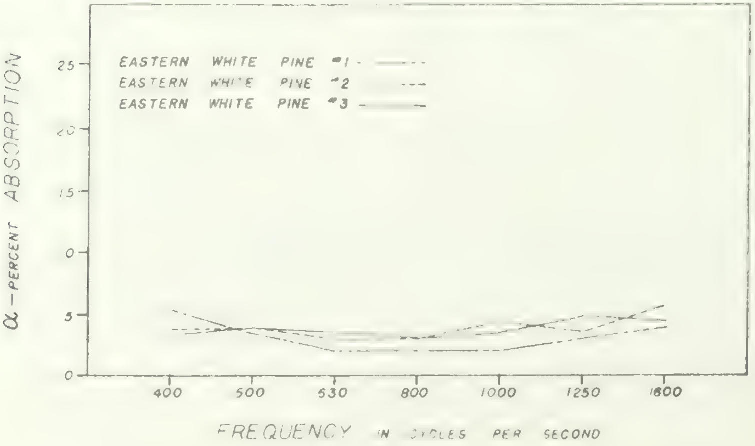


Figure 7.—Absorption of normal-incidence sound by bark of eastern white pine.



pectrometer. The samples were sealed n the holder by pouring paraffin between the sample cylindrical surface and he holder wall. It was determined that reshness of sample had no noticeable ffect on the absorption coefficient.

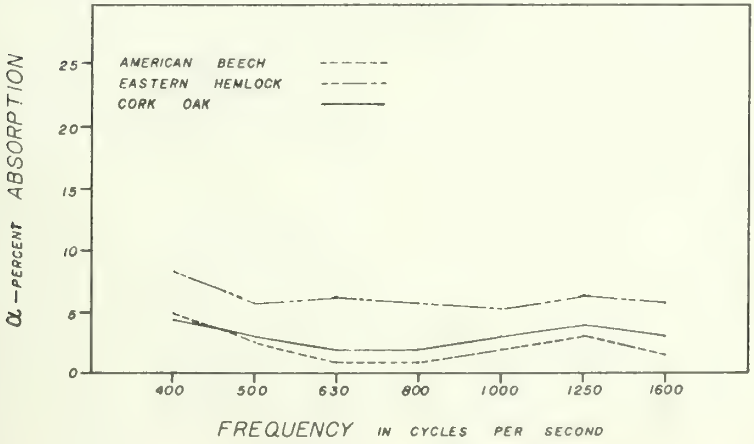
The 1-meter-long impedance tube is ormally capable of providing reliable bsorption data down to frequencies of 25 Hz. However, the presence of iregularities in the bark's surface made advisable to record the maximum and inimum acoustic pressures at a greater stance away from the sample than herwise possible during normal testing. This increased the lower limiting equency, which depends on the length the impedance tube available for easurement, to 400 Hz. The upper limiting frequency, which assures existence of plane waves, is determined by the diameter of the tube. Since sample surface irregularities do not affect the wave pattern far away from the sample, the upper limiting frequency of 1,600 Hz remained the same with the 10-cm-diameter tube.

The absorption coefficients versus frequency for samples of red oak, mockernut hickory, and white pine are plotted in figures 5, 6, and 7 respectively. Each figure shows the results for three samples, each checked for repeatability. The results of the repeated testing of each sample seldom deviated more than 1 percent. The absorption coefficients for all the samples of the three species was less than 10 percent, except for the hickory at frequencies above 1,250 Hz. One hickory sample absorbed a maximum of 12 percent, another 23 percent. The high absorption of mockernut hickory bark may be due to its shale-like layers with spaces between them. The spaces may allow vibration of the individual layers, and the air movement may result in acoustic absorption. This is a mechanical transformation of the incident acoustical energy, and most probably accounts for the additional absorption.

After the tests on oak, hickory, and white pine, we looked for bark characteristics that might alter absorption of sound and selected three other species for testing: American beech, eastern hemlock, and a cork oak (fig. 8). The hemlock sample had a higher absorption coefficient than the beech or cork oak, but all still indicated less than 10 percent absorption.

The percent absorption of the six

Figure 8.—Absorption of normal-incidence sound by American beech, eastern hemlock, and cork oak.



species we tested is quite low and largely independent of frequency. Although our six species provide a fairly wide representation of the characteristics of tree bark, tests on other species would certainly be warranted. Considering the small variation between species, it seems unlikely that any species would be found where the bark absorption would be so high that the sound attenuation of forests (or trees of that species) would be unique because of bark characteristics alone.

Although each tree surface may absorb only a small percentage of the incident wave, this effect is repeated as the sound wave is scattered towards the next tree, and so on repeatedly. The addition of the small absorption percentages is accumulative, yet we do not know how the total bark absorption will compare with that of the shrubs, foliage, branches, or the canopy as a whole. It can be assumed that the multiple-scattering principle will at least make the sound available to more surface area above the ground, since its path length is longer with each consecutive reflection. This gives the ground more chances at absorbing the scattered acoustic energy.

FOREST FLOORS AS A SOUND-ABSORBING SURFACE WITHIN A FOREST

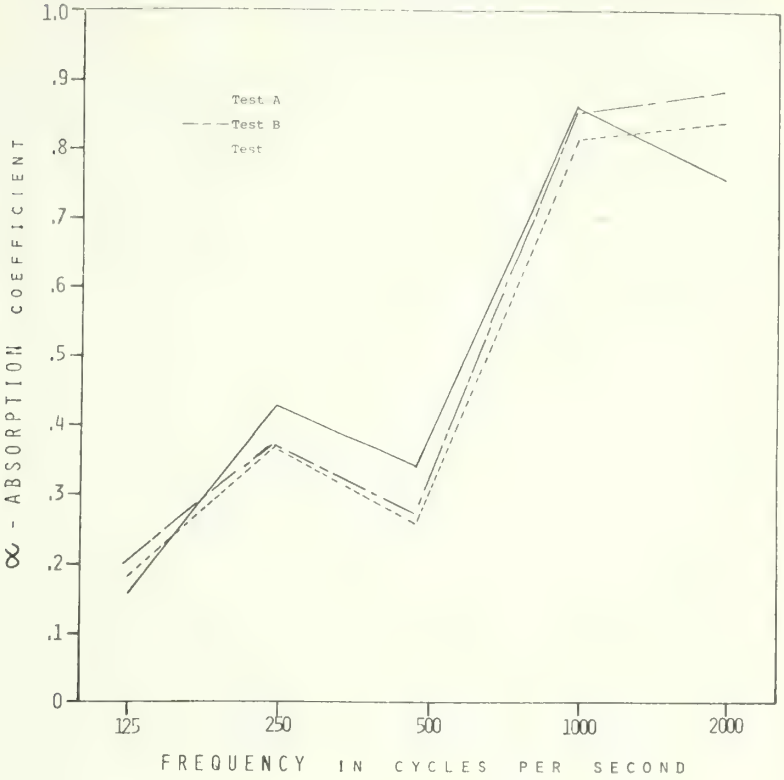
Normal incidence absorption of various forest floors was measured with a specially modified standing-wave tube that could be driven vertically into the ground without disturbing the soil within the 10-cm-diameter tube. The tube was 5½ feet long and permitted measurements in the frequency range of 125 to 2,000 Hz. The loudspeaker was located in a box mounted on top of the impedance tube. A frequency oscillator generated the pure tone sound signals. The ⅛-inch diameter microphone probe was moved longitudinally and centrally into the tube. The sound signals of various vertical locations of the probe inside the 10-cm tube were measured with an octave-band-filtered sound level meter. Again, the maxima and minima, were noted and the acoustic absorption coefficients were calculated. At the end of the five frequency measurements, the sample was ejected and another sample nearby was measurd to give an indication of the repeatability of the test.

All the field equipment is portable and battery operated. We used a four-wheel-drive vehicle to transport the equipment to various measurement sites within the forest.

To determine to what extent the various physical parameters of the soil (porosity, moisture content, surface configuration) will affect the measured absorption coefficient, each parameter was investigated separately. This was done by taking measurements with one parameter as the variable while all the others were held constant. The above was accomplished by noting the soil conditions at the time of the test and matching all but one of these conditions in the repeated testing. This procedure was adequate for determining the range of acoustic absorption controlled by each parameter with respect to the overall absorption of the sample. An analysis of this type of data leads to a better understanding of the mechanisms of absorption. The parameters exerting the most control or yielding the largest absorption variations are then identified quantitatively.

Figure 9 shows a typical curve of the absorption of a sample of the forest floor, the abscissa showing frequency in Hz and the ordinate showing the absorption coefficient α. The absorption shown here displays a primary peak (maximum value) at 1,000 Hz, a secondary peak at 250 Hz and a dip (low value) at 500 Hz. A particular forest-floor absorption curve can be compared to that of another location, in order to obtain an indication of the relative effectiveness of the floor as an absorber over the frequency range of interest.

Figure 9.—Absorption of normal-incidence sound by a forest floor—test for repeatability of measurements on one sample.



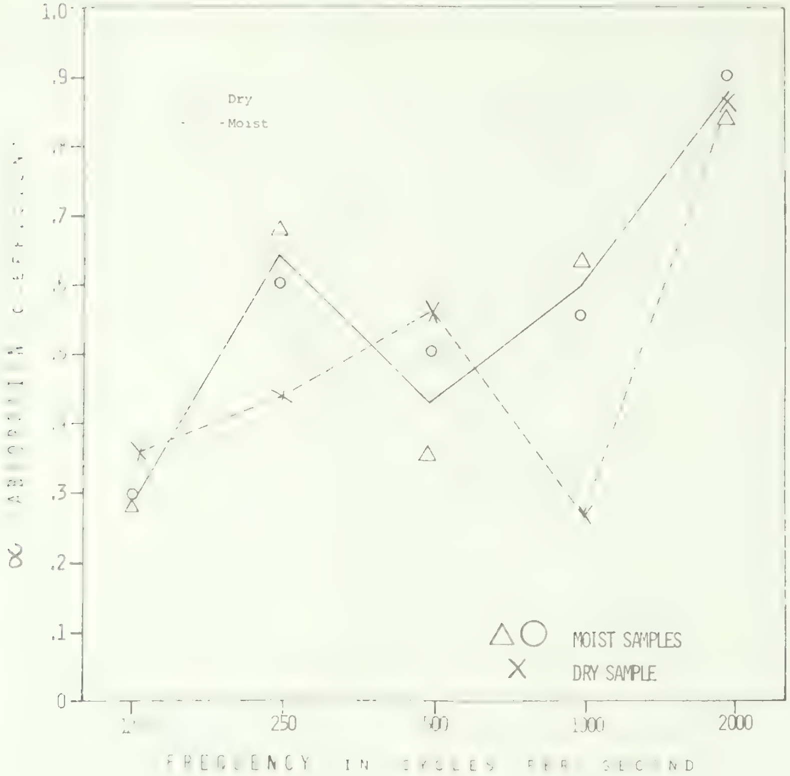
In figure 9, you can see that the three curves are nearly identical. This is the result of a test for repeatability of the same sample before its removal from the impedance tube. This variation is typical of acoustical measurements where data points within a few percent of each other are considered to be within the accepted range of tolerance. If there was a variation at a particular frequency of more than 0.05, the test was repeated before removal of the sample to confirm the results.

Each measurement condition was repeated by testing a comparable sample located approximately 2 feet away. This provides an indication of the variation between samples under the same conditions. The comparison of the absorption curves of either two or three measurements confirmed good repeatability for nearby tests.

A sample was tested when the ground was dry, without any rain for 2 weeks. The same locality was then retested when the ground was moist, 2 days after a heavy rain. The absorption curves for these tests are displayed together in figure 10. Since the sites were identical, we assume that all parameters remained constant except the moisture content of the soil. There is an indication from these two absorption curves that the ground was relatively more efficient at absorbing sound when it was moist than when it was dry.

An examination of several other sets of comparisons for identical localities with varying moisture conditions revealed some interesting trends. The sound absorption by the ground was noted immediately after rain; the amount of absorption increased after a couple of days of drying and then pro-

Figure 10.—Absorption of normal-incidence sound — same forest floor with two different moisture contents.



gressively decreased day by day as drying progressed. When the ground became saturated with the next rainfall, the cycle started over again. Thus, the time for maximized absorption was about 2 days after a rainfall.

The magnitude of the variations of acoustic absorption in the comparisons was, of course, frequency- and time-dependent, and the variations at some frequencies were much larger than at others. An overall increased or decreased absorption for the frequencies considered was the criterion for evaluation. An explanation for this observed phenomenon presumably is a change in the porosity of the ground as it becomes saturated with water. It is known that the porosity of an acoustically absorbent material is an important factor in the absorbing mechanism. These results indicate that the moisture content is a parameter to be considered in further investigation.

The determination of the effects of absorption by grass were measured in the manner just mentioned. Figure 11 shows the absorption curves of two samples, one of bare soil and the other with several inches of dry matted grass. As can be seen by comparison, the grass-covered sample provides more absorption and would attenuate noise more effectively. Other comparisons of similar sets of curves show the same results. It should be noted, however, that though the planting of grass would add some absorption to the environment, this might in turn affect the absorption by the soil. If the grass were to change the moisture content of the soil through its growth process, or through any changes in the irrigation of the forest floor, this change in moisture would affect the soil

Figure 11.—Absorption of normal-incidence sound for grass-covered and bare soil.

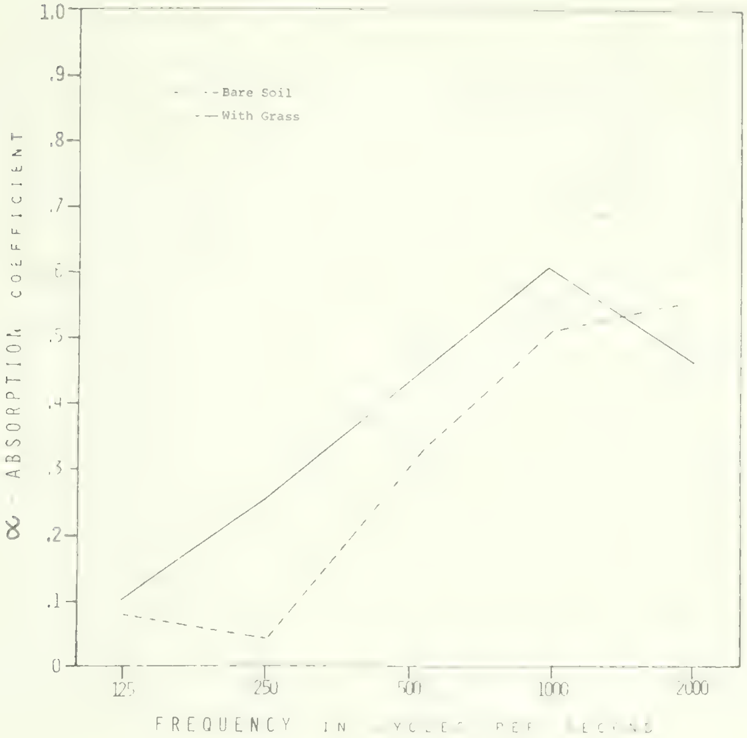
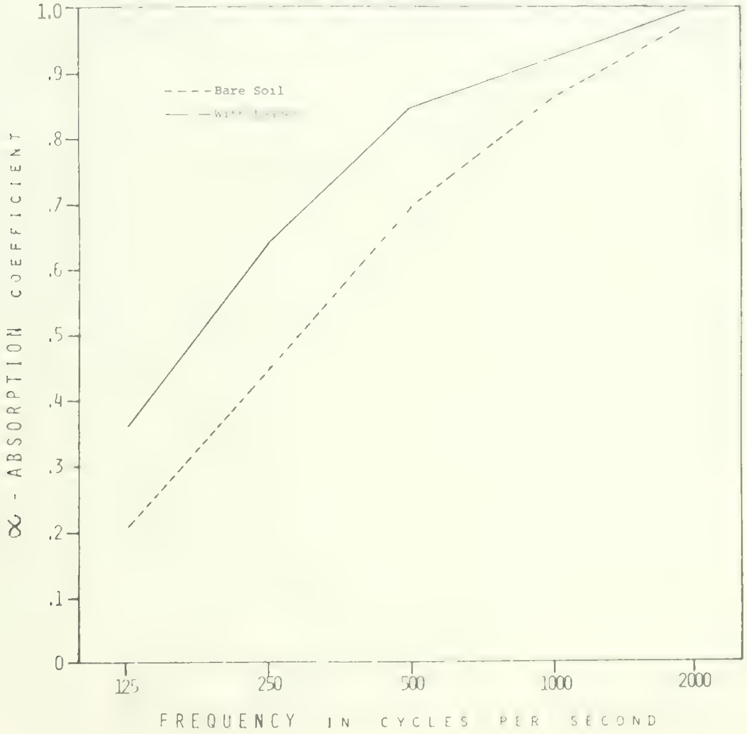


Figure 12.—Absorption of normal-incidence sound for soil with leaf litter and for the same soil without a litter layer.



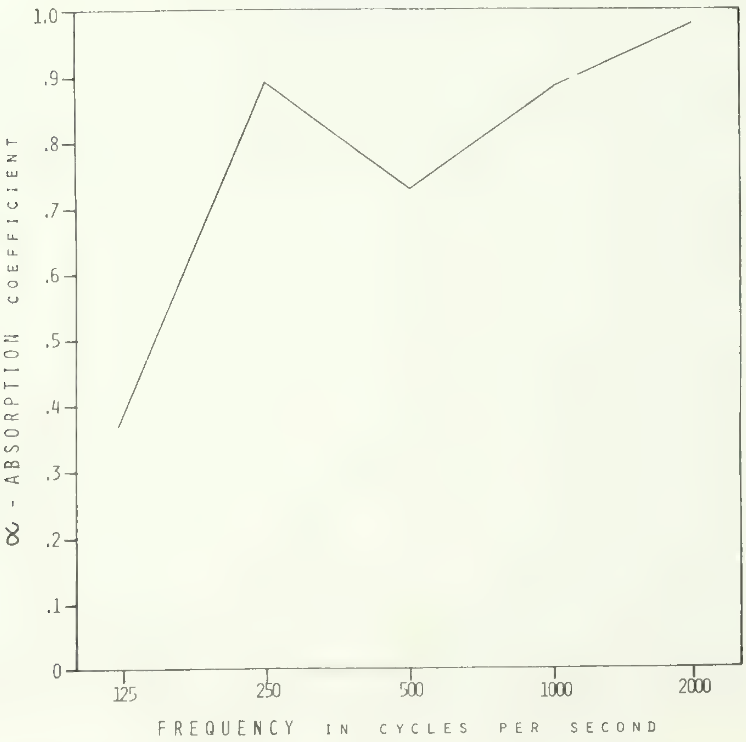
absorption. Whether or not this factor increases absorption has not been determined as of this time.

Similarly, the contribution of the absorption of the leaf layer in a deciduous forest was investigated. One such set of comparisons appears in figure 12. Like that of grass, the leaf layer adds to the absorption and in comparable amounts. Various isolated tests determined that the thickness and state of decay of the leaf layer were important factors. The comparisons of these tests show that, the thicker the layer of leaves present, the higher the percentage absorption obtained for a similar moisture content and thus the greater attenuation that would be provided. Similar tests were conducted in a coniferous forest with similar results.

In an attempt to investigate the absorption of the forest floor with a moss covering, the preceding method of testing a particular area with and without the vegetative covering did not give consistant or repeatable results. This may be due in part to the fact that the moisture content of the soil where moss grows is probably greater than that of nearby soil where there is no moss. Thus the inconsistancies would depend not only on the absorption by the moss, but also on the variations in absorption provided by different moisture contents of the soil underneath. Rather than a comparison in this case, the results can be summarized by stating that the absorption by a moss-covered ground is greater than that of bare soil or soil covered with leaves. A typical result can be seen in figure 13, a curve showing the absorption of moss-covered loam.

The results provide good indications of the normal incidence absorption characteristics of a typical forest floor. Forty-seven samples were tested, many of which were similar, providing indications of repeatability of the results.

Figure 13.—Absorption of normal-incidence sound by a moss-covered soil.



Some tests occurred with nonrepeatable results which we believe were caused by sample peculiarities. For example, a few samples were found to include rocks and roots. These samples were rejected from the analysis.

The question then arises, why forests do not attenuate sound to the magnitude that would be expected from all these results, as the percent absorption is quite high in some cases. This situation occurs because not all of the sound that passes through the forest actually comes in contact with the ground. Only those rays that strike the forest floor are partially absorbed by the ground. Here is where the trees become effective, as they act as sound scatterers, increasing the effective path length of each sound wave as it traverses through the forest. This gives the porous ground more chances to absorb the noise.

The results confirm that the ground is a significant absorber of sound in the forest. Moisture content and ground-cover structure have been found to cause variations in the absorption. The quantitative relationships of the effect of moisture, soil porosity, soil surface makeup, and extent of decomposition on absorption still need to be established.

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Evaluating Effects of Vegetation on the Acoustical Environment by Physical Scale-modeling

by RICHARD H LYON, CHRISTOPHER N. BLAIR, *and* RICHARD G. DeJONG, *respectively professor of mechanical engineering, graduate student, and research assistant, Massachusetts Institute of Technology, Cambridge, Mass. The authors thank the National Science Foundation for its support under Project RANN in the development of modeling techniques used in this study.*

ABSTRACT.—It is generally assumed that vegetation is beneficial acoustically, as well as esthetically, in that it may act as a shield to reduce highway noise impact on a community as in a sound absorber to reduce reverberant noise levels in city streets. Contradictory evidence exists, however, that noise may be increased because of vegetation. We performed field studies and laboratory scale-model experiments to study interaction between sound-scattering by trees and shadowing by barriers. The studies indicate that, while barrier effectiveness may be reduced by addition of trees, propagation through a stand of trees may provide small noise reductions.

RECENT STUDIES of the behavior of vegetation placed on noise barriers have produced contradictory results. A report by Cann and Manning *(1974)*, based on model studies, suggests that trees placed on top of barriers can reduce barrier effectiveness, while field studies by Cook and Van Haverbeke *(1974)* show increased barrier effectiveness with trees. It was decided to use model studies to resolve this discrepancy.

Until recently, the use of scale models in acoustics has been limited to use in the design of concert halls and auditoria. However, within the past 6 years at MIT, modeling techniques have been successfully applied to problems in outdoor noise propagation by DeJong *(1974)* and Blair *(1975)*.

FIELD STUDIES

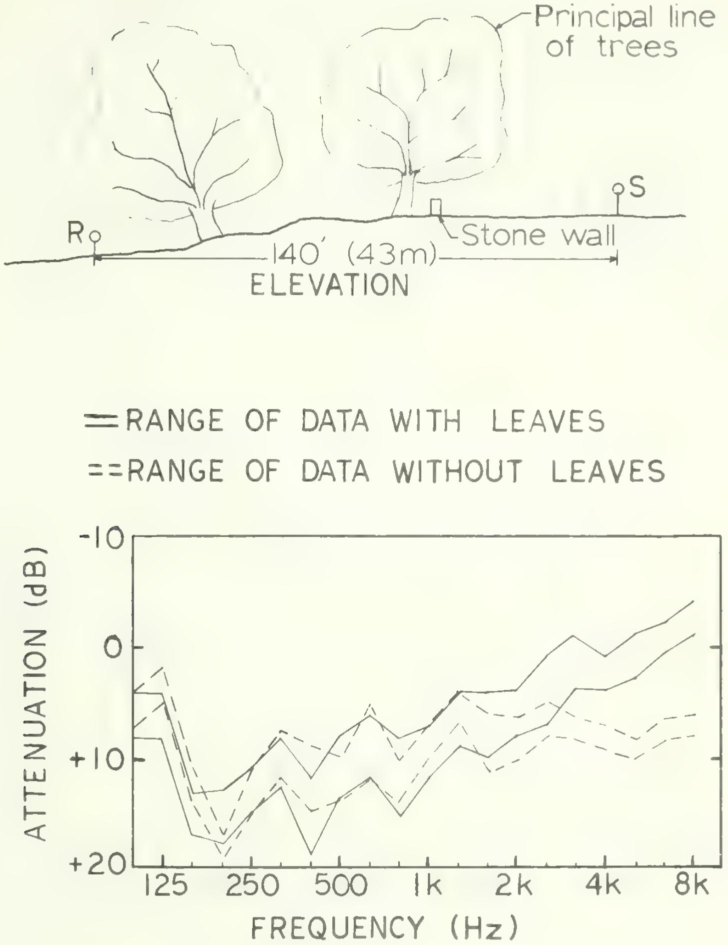
To evaluate the results of the planned model studies, it was necessary to conduct full-scale tests on vegetation configurations not fully covered in the literature, especially those in which the canopy is above the line of direct propagation.

The noise source used was a 12-gage shotgun, carefully studied for its noise spectrum characteristics. The pressure pulse was recorded on magnetic tape, using a Nagra tape recorder and a B&K 1-inch microphone.

Measurements were taken in late spring and early summer to assess the effects of the maple leaves. Care was taken to insure that ground conditions were similar on all measurement dates.

One of the sites chosen for propagation studies was a line of maple trees located at the top of a hill (fig. 1). Acoustic measurements were taken at various points beyond the tree line. Although there was a stone wall along the tree line, the tip of the shotgun muzzle was visible at all receiver points. An example of the measurements shows that the observed spectra with and without leaves begin to diverge above 2,500 Hz corresponding to a wavelength of about 5 inches (12.7 cm), approximating the tip-to-tip breadth of the leaves. The high-frequency excess attenuation observed with leafless trees may be attributed to backscatter from the trunks

Figure 1.—Excess attenuation in the sound propagating across a line of maple trees.

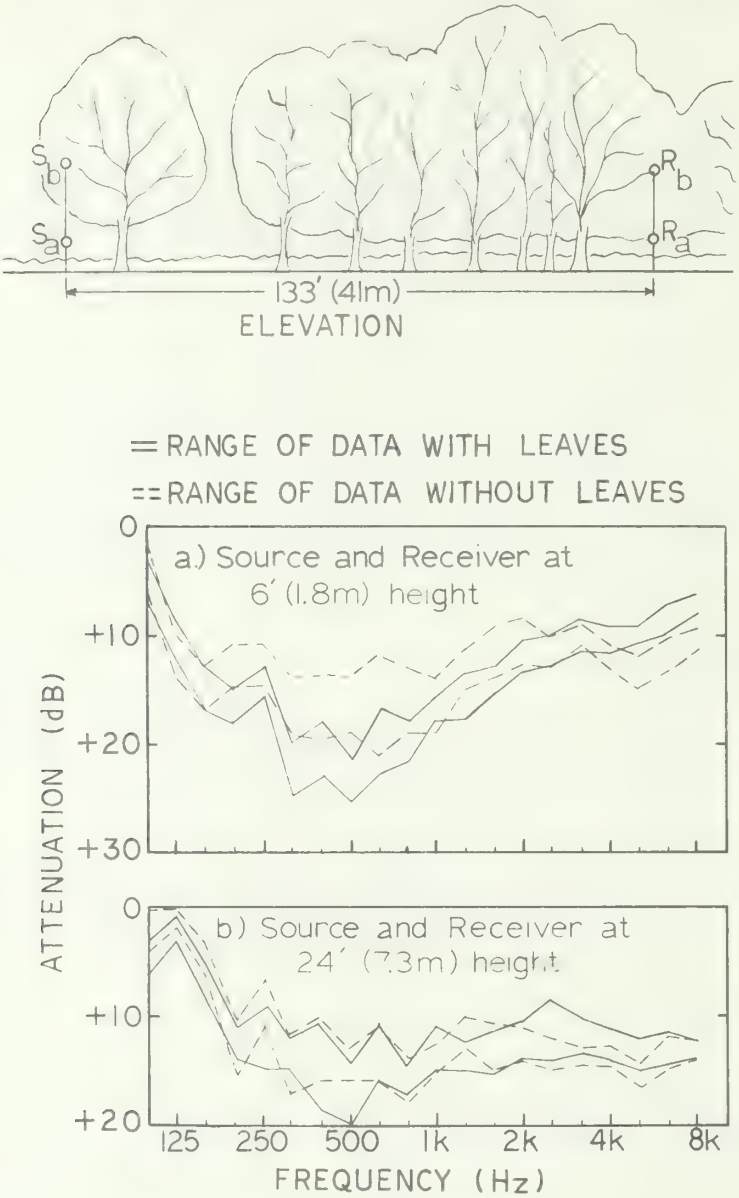


and branches and the effects of the stone wall almost intersecting the line of propagation.

The backscattering effects of trunks and branches were further studied in the following experiment. Sound propagation was measured along a line of trees at various heights in the canopy (fig. 2). Shotgun and microphone were suspended in the trees, and the line of sight was completely obscured by the trunks and branches. The large excess attenuations observed are due to backscattering from trunks and branches. At the position just below the canopy, leaves scatter some additional high-frequency sound to the microphone. In the canopy, however, leaves appear to have little effect. One may hypothesize that any additional attenuation offered by the leaves along the line of propagation is offset by scattering from leaves in other portions of the canopy.

In a third example of propagation under the canopy (fig. 3), shots were fired at various distances into a homogeneous mature maple stand and picked up by a microphone on the edge of the woods. At all times there was unobstructed visibility from source to receiver. As before, the leaves have a pronounced effect above 2,000 Hz, and

Figure 2.—Excess attenuation in the sound propagating through a canopy of maple trees.



backscattering from the trunks of leafless trees results in high frequency attenuations. The large dip around 315 Hz is due to ground effect.

MODEL STUDIES

Model studies were then undertaken to facilitate more detailed studies of various tree-barrier configurations. Scale-modeling involves reducing all the dimensions in the system being studied by a scaling factor. Acoustical modeling requires that the wavelength of the sound be reduced by the same ratio as all other dimensions. This is most easily done by increasing the frequency of the sound used. Then, for example, in a 1:32 scale model, a full-scale frequency

Figure 3.—Excess attenuation in the sound propagating under a canopy of maple trees.

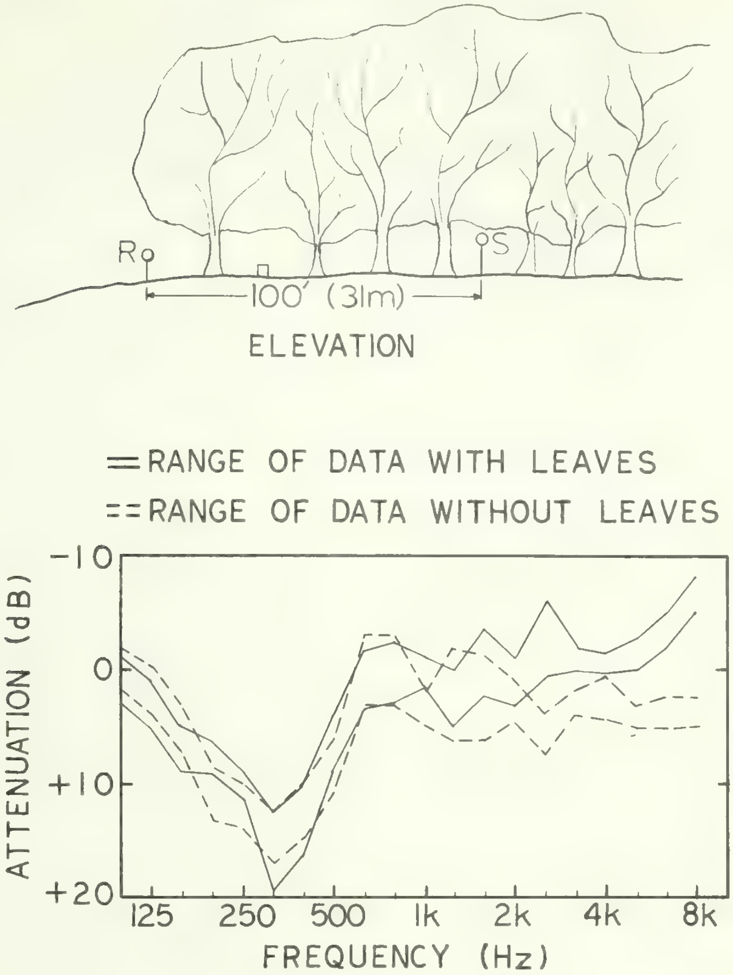
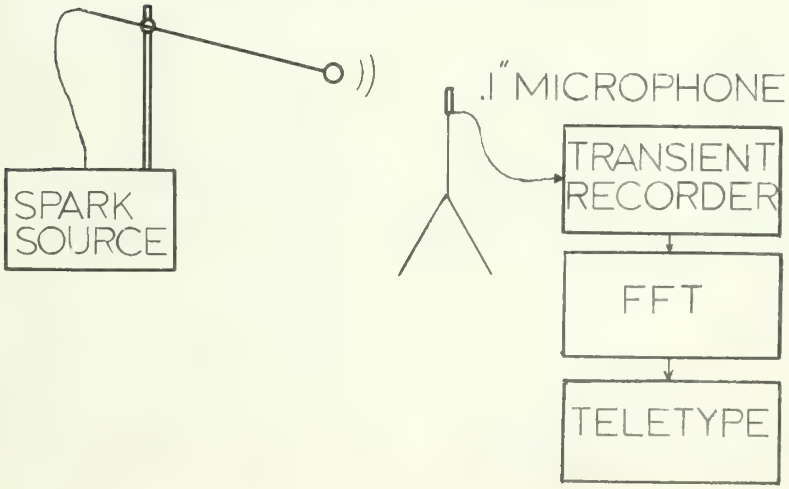


Figure 4.—Elements of the modeling system.

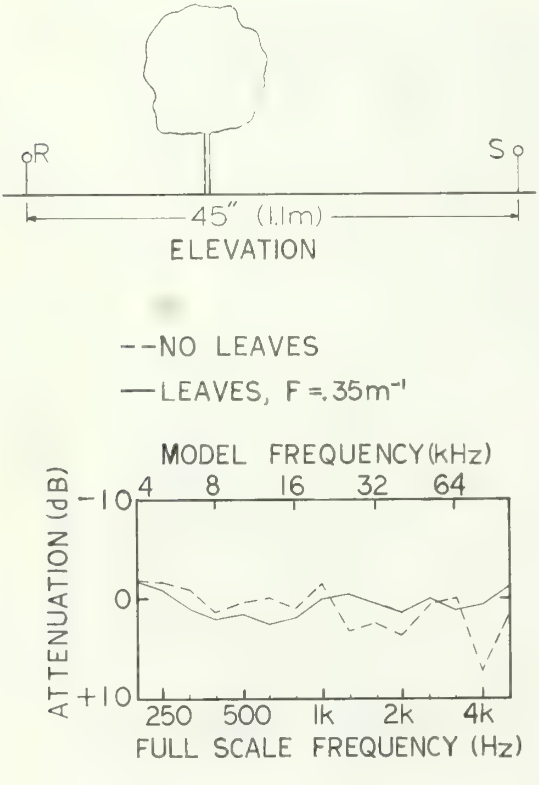


of 1,000 Hz would be modeled with 32 kHz.

To produce noise at these high frequencies, an electric spark discharge in air was used (fig. 4). Operating at 3,000 volts, this spark source produces an acoustic impulse with energy over a frequency range of 4 kHz to 150 kHz.

The sound was detected with a 1/10-inch piezoelectric microphone and recorded in a digital transient recorder. The recorder was interfaced with a digital computer, which performed a fast fourier transform (FFT) on the signal. The FFT values were then combined into a ⅓ octave band level and printed out on the teletype. These levels correspond to the levels that would be obtained using a steady state source in an anechoic chamber. However, by using an impulsive source, an anechoic chamber is not needed since the reflections off the walls arrive at the microphone after the desired signal is recorded. An oscilloscope was used to monitor the recorded signal to observe the arrival times of the pressure pulses at the microphone. This allowed the identification of different propagation paths from the source to the microphone.

Figure 5.—Excess attenuation in the sound propagating across a line of model trees on a flat plain.



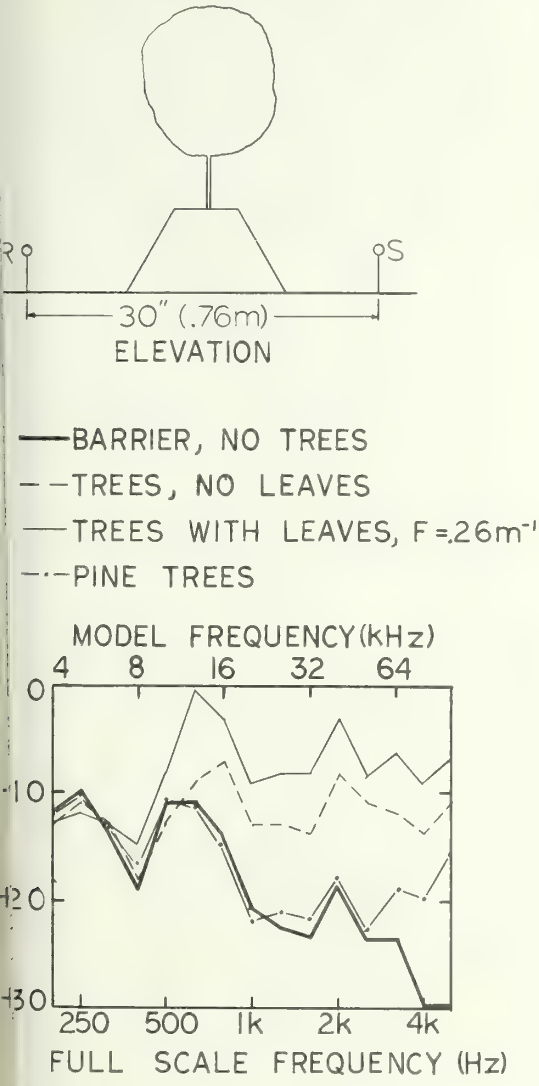
The materials used in constructing the models were selected to have the same absorption at the scaled frequencies as the real materials being simulated have at audio frequency. The ground was modeled with a soft pressed fiberboard covered with flocked paper.

The model was constructed to a 1:20 scaling to allow analysis of full-scale frequencies as high as 5,000 Hz. Using trees actually encountered in the field studies as subjects, models were built representing 14-foot (4.3 m) pine and 30-foot (9.1 m) maple trees. Serpentine was used to model maple leaves; although it did not perfectly model leaf characteristics found in the field, the serpentine was determined adequate for qualitative analysis of leaf effects. Various leaf-area-per-unit-volume densities (F) could be modeled by changing the amount of serpentine placed in the canopy.

The basic experimental approach was to set up a line of trees in various configurations, with and without barriers, and measure the insertion loss of the vegetation at various distances behind the tree line. Results of excess attenuation across a line of model trees on a flat plain (fig. 5) are in good agreement with observed field data. Without leaves, the tree trunks appear to offer some attenuation above 1,000 Hz, but the presence of leaves scatters additional acoustic energy downward, resulting in reduced or even negative attenuation.

Next the attenuation of a barrier with and without trees on top was measured (fig. 6). In the case of the model maple trees, the scattering contribution of the

Figure 6.—Attenuation of sound by a barrier with and without trees on top.



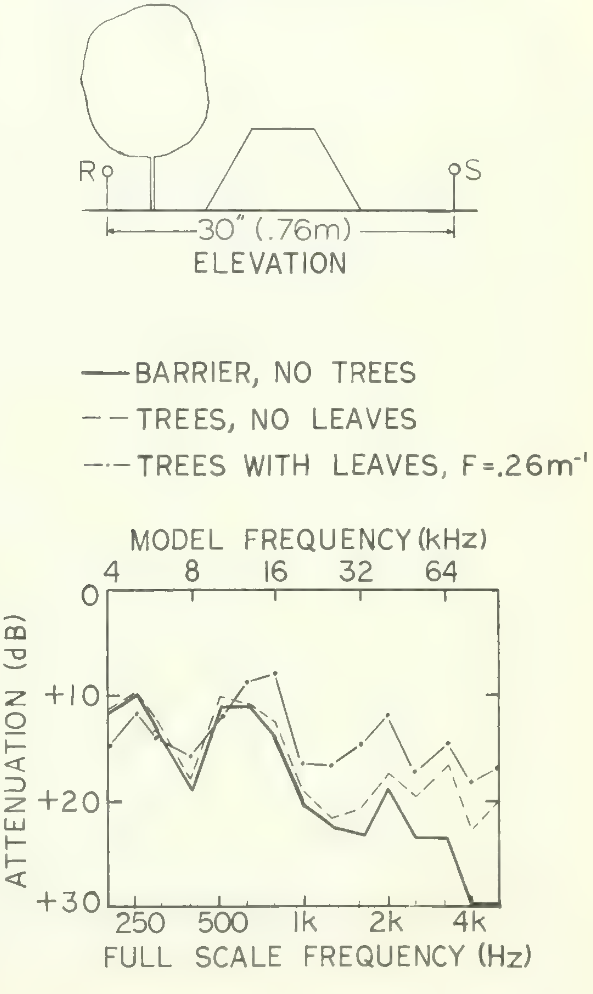
leaves occurs at a lower frequency than noted in the field data. This anomaly is due to the imperfect modeling characteristics of the serpentine, which is a long continuous tape rather than many small patches. The negative attenuation contributions of leafless maples are due to the scattering off of the major horizontal branches. The pines, which scatter sound at a higher frequency corresponding to the pine's smaller and more concentrated branches, display similar characteristics. As can be observed, planting a single row of trees on top of a barrier can be devastating to the barrier's effectiveness.

By moving the trees from the top of the barrier to behind it, the barrier effectiveness is not so severely damaged (fig. 7). Only about half of the canopy is exposed to direct sound from the noise source explaining this result.

DISCUSSION

The frequency dependence of the scattering effectiveness is consistent with dimensions of the scattering bodies: the smaller the leaf or branch, the higher

Figure 7.—Attenuation of sound by a barrier with and without trees along the side.



the frequency at which scattering becomes effective. Thus the presence of a plant with small branches and leaves will not appreciably affect noise levels in the frequency range of primary interest in noise-control circles.

Plant geometry also appears to be important. A tree with vertically hanging leaves and few horizontal branches, placed on top of a barrier, will scatter less sound downward into the shadow zone behind the barrier than other tree configurations.

The effects of the introduction of vegetation on the sound field beyond it can be generalized graphically (fig. 8). The leaves and branches scatter a portion of the incident acoustic energy t the side and backwards, resulting in shadow zone behind the vegetation.

The introduction of a solid barrie between source and receiver complicate the analysis somewhat. The leaves an branches of the tree may now be considered as noise sources, and any portion of the canopy not shielded from th receiver will reduce the barrier's effectiveness through scattering.

However, if the barrier extends upward into the shadow zone behind th tree (fig. 9) another counteractin mechanism becomes important. Th

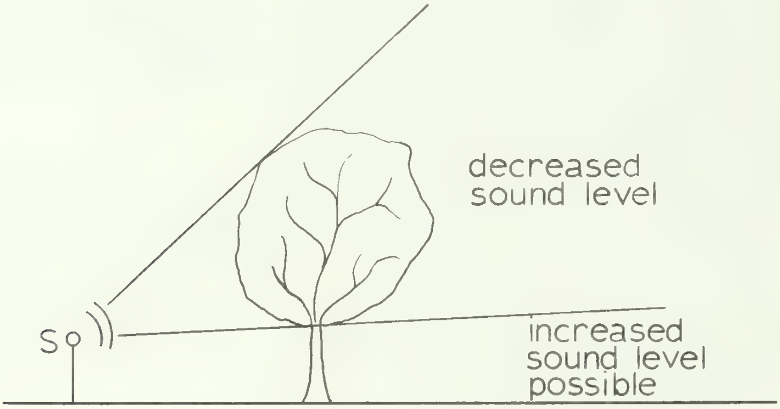


Figure 8.—The screening of sound by vegetation.

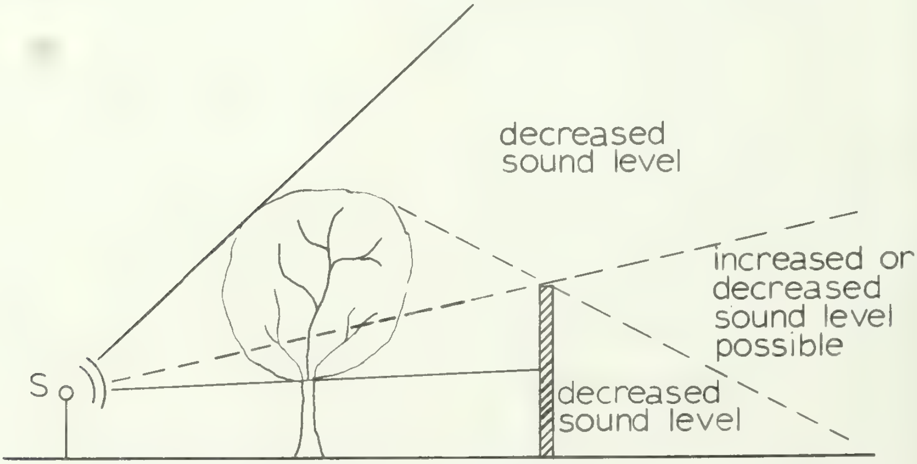


Figure 9.—Effects of vegetation upon barrier performance.

noise observed at the receiver point is dependent on the sound-field conditions above the barrier. If this sound field is reduced in intensity due to screening effects of the tree, barrier effectiveness is increased. Estimation of these scattering and screening components is essential in predicting the behavior of tree and barrier configurations. Since theoretical calculations are complex, this is best done by using model studies.

CONCLUSIONS

The results of this report show that scale-modeling can be a useful tool in evaluating the effects of vegetation on the acoustic environment. In particular, the positioning of trees around a barrier has an important influence on the barrier's effectiveness. Further work is being done at MIT to develop a simplified modeling-instrumentation system to facilitate the general use of modeling for the evaluation of a wide range of community noise problems.

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Propagation of Noise over and through a Forest Stand

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This research was supported in part by funds provided by the Northeastern Forest Experiment Station through the Pinchot Institute for Environmental Forestry Research, Consortium for Environmental Forestry Studies.

ABSTRACT.—Measurements of the two-dimensional acoustic field in a forest resulting from a source located outside the forest indicated that the attenuation pattern near the ground is significantly different from the pattern higher up in the forest. The patterns of attenuation support the recent theory that the forest floor is the main absorber of acoustic energy in the forest.

SOUND RADIATING from a point source decreases in sound pressure level (SPL) 6 dB for each doubling of distance due to spherical spreading of the wave front. Any additional reduction in SPL due to the presence of ground, vegetation, buildings, etc. is usually referred to as excess attenuation.

Measurements of excess attenuation within 10 feet of the forest floor indicate that the reduction in SPL due to the presence of the forest is approximately 6 dB per 100 feet of forest *(Bjornson 1971, Herrington 1974, McLaughlin 1975)*. These same studies indicated that the variation in SPL near the forest floor was not characteristic of the acoustic field in the forest at higher levels. The objective of our study was to describe the acoustic field within and over a forest stand in a vertical plane parallel to the propagation of sound from a point source.

METHOD

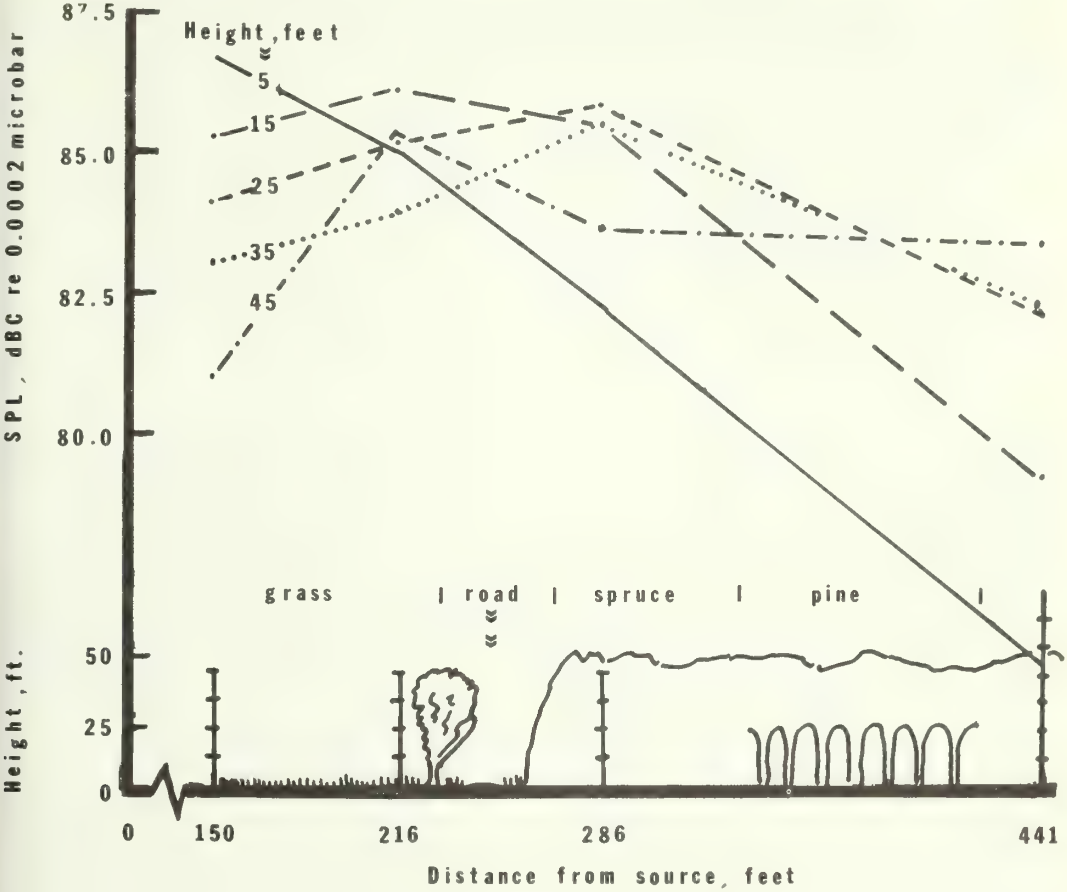
Wide-band pink noise (a spectrum of noise with equal energy per octave of frequency) was broadcast from a folded-horn speaker toward the edge of a coniferous plantation (fig. 1). Along the axis of propagation, five towers were erected. Two of these towers were located outside the forest, one was located on the edge of the forest, and two were located within the forest.

Microphones, which were attached to pulley systems on each tower, were used to measure the sound pressure level at the heights indicated (fig. 1). The pink noise (signal) received at each microphone was recorded on magnetic tape at the test control center. Both ambient noise—that is, the noise naturally present in the environment—and the signal were measured for each tower-height combination during 14 field-measurement periods. These periods were approximately 30 minutes in length. The field measurements were made under a wide range of meteorological conditions during the summer of 1974. The recorded data were subsequently analyzed on a real-time analyzer, using an averaging time of 128 seconds. In this fashion the acoustic field in a vertical plane containing the axis of propagation was determined.

For each measurement, meteorological data (temperature and temperature profile, wind and wind profile, relative humidity and solar radiation) were also recorded.

The forest consisted of a plantation made up of parallel bands of Norway spruce *(Picea abies)* and red pine *(Pinus resinosa)* 1-chain (66 feet) wide, ori-

Figure 1.—Excess attenuation at five heights for acoustic energy propagating over and through a forest edge. Included is a diagram of vegetative features along the path and the location of the towers from which measurements were made.



ented at an angle of 20 degrees to the axis of noise propagation. The spruce presented a very dense tangle of dead branches below the live crown, while the pine was naturally pruned to a height of approximately 30 feet. The edge of the plantation was defined by a road and a partial row of deciduous trees (fig. 1).

RESULTS AND DISCUSSION

Figure 1 shows the average corrected SPL at several heights as a function of distance into the plantation. Corrected SPL was calculated by adding to the recorded data the loss due to spherical spreading of the wave front (6 dB per doubling of distance). Thus, a horizontal line in figure 1 would indicate no excess attenuation.

SPL increased with height at the 150-foot tower and showed a mixed pattern at the plantation edge (216 feet). Measurements of the directivity of the horn used to generate the acoustic signal indicated that this increase in SPL with height was not due to directivity of the speaker. The conclusion, therefore, is that this pattern must be due to reflection of acoustic energy from the edge of the forest. The generally increasing SPL between the 150-foot and 216-foot towers supports this contention. At a height of 5 feet there was little foliage at the edge, and there was a decrease in SPL at the 5-foot height between these points. The further increase in SPL between the 216-foot and 286-foot towers for heights of 25 and 35 feet may also be due to reflection of acoustic energy, but this is less clear than for the edge condition.

Within the forest there is a steady and rapid decrease in SPL at the 5-foot height. At higher elevations, however, the pattern is not as clear. The 45-foot height, which was just about at the top of the canopy, shows very little attenuation with distance; while the levels measured within the canopy do show some attenuation with distance. The 34-foot level, which was distinctly within the closed portion of the canopy, showed the strong attenuation between 286 and 441 feet from the source.

Two-way analysis of variance (height and distance) of the corrected SPL data showed, as might be expected, that total attenuation increases with the distance from the source. The analysis of variance also showed that there was significant variation of the attenuation pattern with height and that there was a significant interaction between height and distance. Grouping of the data in the analysis of variance procedure showed that there was no significant difference between the attenuation patterns at the 15-, 25-, 35- and 40-foot levels, but that there was a significant difference between the attenuation pattern at 5 feet and at the higher levels That is, the pattern of attenuation near the ground is not the same as that which exists at 15 feet and above.

Based on their measurements of the acoustic absorptivity of bark, Reethof *et al. (1975)* have proposed that tree stems and branches are scatterers of acoustic energy and that absorption takes place mainly at the ground surface. Our results plainly support this argument and indicate further that there may be some attenuation in the thickest part of the canopy also.

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Some Physical and Psychological Aspects of Noise Attenuation by Vegetation

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ABSTRACT.—The physical mechanisms governing sound attenuation by foliage, stems, and ground are reviewed. Reflection of sound energy is found to be the primary mechanism. In addition, new experimental results are discussed that help to quantify the psychological effect of a plant barrier on perceived noise level. Listeners judged the loudness of noise transmitted through hemlock trees and through a minimal fence barrier to differ by as much as 7 dB even though the sound level at the listener was the same.

CONSIDERABLE MEASUREMENTS OF NOISE muffling by plants have been made. To properly interpret these measurements, a firm understanding of the physical mechanisms of sound attenuation by plants is required. For example, many of the differences in sound attenuation by plants found by earlier workers *(Eyring 1946, Wiener and Keast 1959, Embleton 1963)* can now be reconciled by physics *(Aylor 1972a).*

Besides physical effects, there can be psychological effects of plant barriers on the perception of noise. The visual shielding of a source by plants may have a beneficial effect for reducing the annoyance of noise *(Kurze 1974, Herrington 1974).* So far, this potential psychological effect has not been quantified.

PHYSICAL EFFECTS

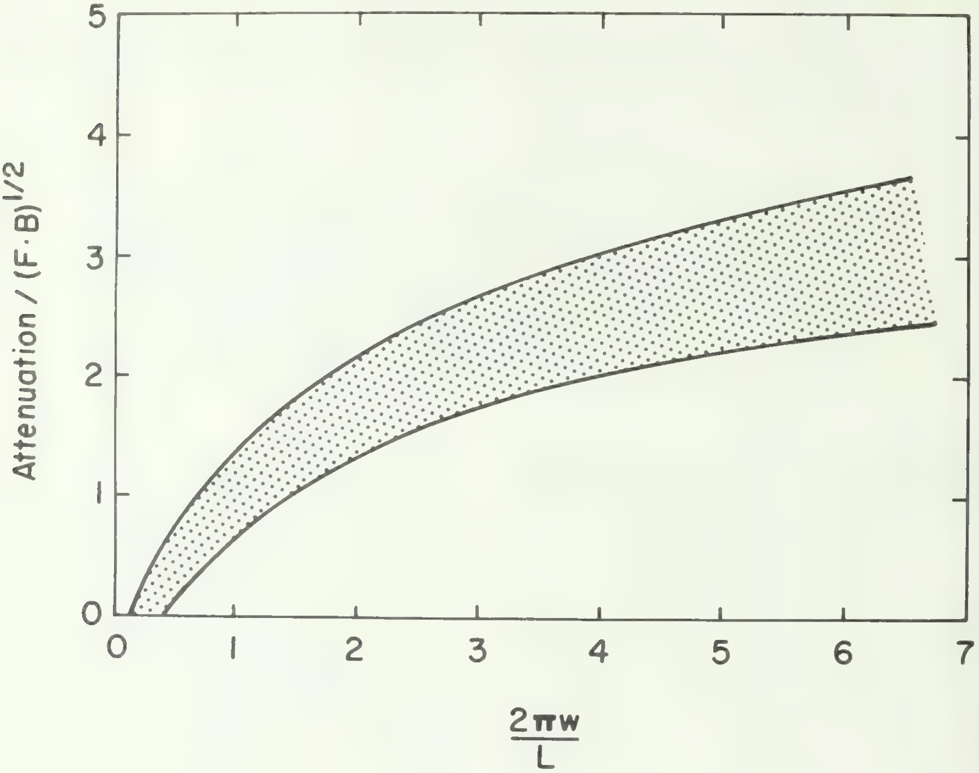
Plants can attenuate sound by reflecting energy, by absorbing energy in the viscous and thermal boundary layers near the plant surface, or by internal damping of sound-driven oscillations of branches or stems. Moreover, plants can modify the texture of the ground and thus alter sound attenuation by ground. Microclimate, which has profound effects on sound transmitted outdoors, will not be discussed here. For a review of meteorological effects on sound transmission see Ingard *(1953).*

Scattering by Foliage

Sound is attenuated by foliage primarily by reflection or scattering. This conclusion is supported by the following observations: the attenuation of sound transmitted through foliage is much larger and increases more rapidly with sound frequency than predicted for absorptive mechanisms *(Aylor 1972a, Embleton 1963);* attenuation does not increase in direct proportion to the amount of foliage, but rather less rapidly; attenuation of a given sound frequency increases with the width of the leaf *(Aylor 1972a and 1972b).* Still further evidence indicating that foliage attenuates sound mainly by scattering, rather than by absorption, was deduced from measurements of sound reverberation between buildings covered with ivy *(Aylor et al. 1973).*

Clearly, the energy transmitted through a canopy of leaves is scattered many times, and the mathematical solution of this multiple-scattering problem is evasive. Fortunately, however, the reduction of a direct beam of sound by foliage can be estimated in terms of the leaf area per unit volume of canopy, leaf width, breadth of the canopy, and wavelength of the sound (fig. 1). Because leaves diffuse concentrated sound effectively but absorb little, best results are obtained when a screen of vegetation is placed on a line of sight between a

Figure 1.—The shaded region gives an estimate of sound attenuation (dB) by foliage. F is leaf area per unit volume of canopy (m^{-1}), B is breadth of canopy (m), w is leaf width (m) and L is the wavelength of sound (m).



direct source of sound and a listener and closer to the source than the listener. Sound that is already diffuse is reduced relatively little.

Scattering by Trunks and Branches

Since trunks and stems are quite rigid, little energy is scattered when the wavelength of sound is large compared with their diameter. However, in the high frequency limit — when the wavelength is small compared to the stem diameter — the amount of scattered energy can be significant. For this limit, at the far edge of a dense forest, the attenuation A varies *(Aylor 1972a)* according to:

$$A \sim Z + \tfrac{1}{2} \log Z \qquad [1]$$

where $Z = 4\,N\,a\,y$ is the dimensionless scattering pathlength. N is the number of trees per unit land area, a is the average trunk radius, and y is the distance into the woods. This approximate expression is not valid for small Z.

The values of the parameter Na for most wooded sites range from $1 \times 10^{-2}\ m^{-1}$ to $5 \times 10^{-2}\ m^{-1}$. The predicted attenuation due to stems for high sound frequencies at 100 m or so distance agrees fairly well with measurements *(Aylor 1972a)*. Finally, the principles of scattering show why visibility is a poor estimate of sound attenuation by trees. Because of the much shorter wavelength of light compared to that of sound, visibility is greatly reduced by small stems and needles. However, because of their small size, they do not scatter much sound.

Attenuation by Ground

When the source and receiver of sound are both near the ground, sound attenuation exhibits a maximum at a specific frequency *(Ingard 1953)*. This attenuation is due primarily to destructive interference between the direct and reflected sound at the receiver, and it depends on the source and receiver heights, source-to-receiver distance, and the acoustic impedance of the ground surface.

The phase of the reflected wave is retarded with respect to the direct wave by two effects. First, there is a delay due to the increased distance traveled by the reflected energy. In addition, for porous surfaces there is a phase lag due to interaction of sound with the surface. Because the ground is porous, it reflects sound only after a slight delay, while the air in the pores is being compressed. This delay, combined with the longer distance traveled, causes acoustic interference at the receiver. In general, the more porous the soil, the longer the delay in compressing air in its voids. The result is that the peak attenuation occurs at lower frequencies over more porous soils *(Aylor 1972a)* and is less dependent on source-receiver separation. Moreover, far from the source with both source and receiver near the ground, i.e. grazing incidence, ground attenuation is very nearly 6 dB per doubling of distance *(Ingard 1953, Aylor 1972a)*.

PSYCHOLOGICAL EFFECTS

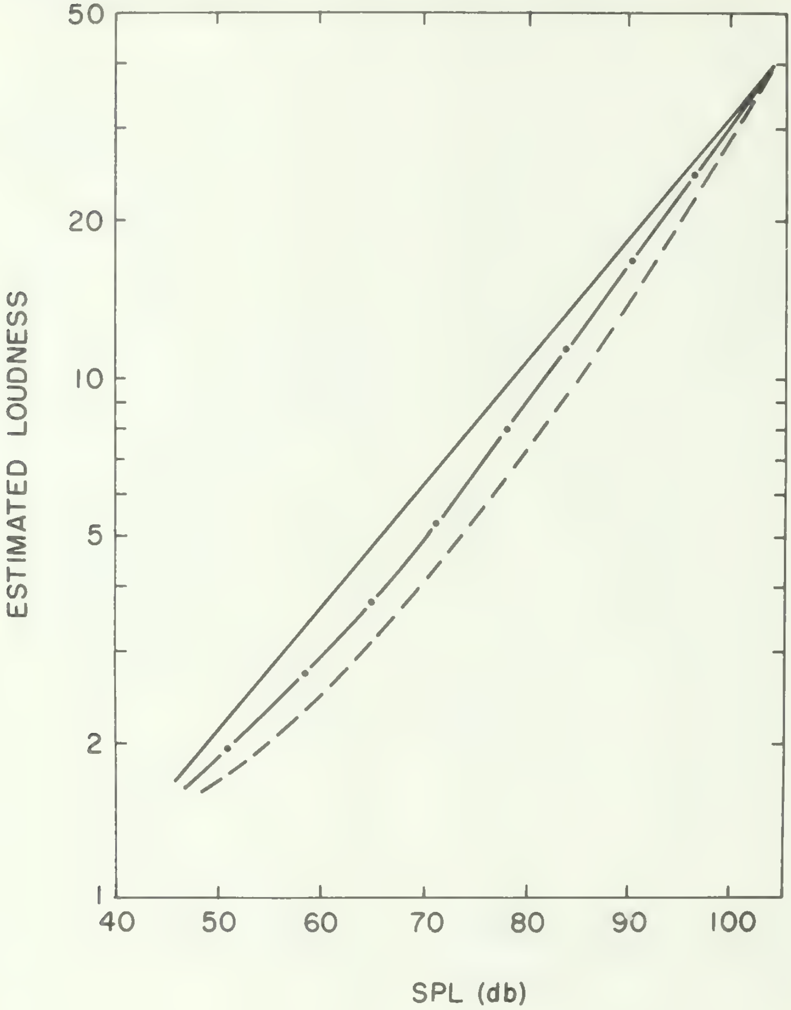
Although a narrow barrier of plants may give measurable attenuation of sound energy, some people believe that the visual shielding of the sound source may nevertheless have a positive or beneficial, psychological effect for reducing noise *(Kurze 1974 and Herrington 1974)*. To help define the interaction of sight and sound on perceived noise levels, Lawrence E. Marks of the John B. Pierce Foundation Laboratory in New Haven, Connecticut, and I asked human observors to scale numerically, by the method of magnitude estimation *(Marks 1974)*, the relative loudness of a narrow band of noise transmitted outdoors through barriers of different solidity.

Thirty subjects were asked to compare the relative loudness of a third-octave of noise at 1000 Hz transmitted to them through each of three barriers of contrasting physical characteristics or without an intervening barrier. The subjects were instructed to assign any number they wished to the first stimulus but to thereafter assign numbers in proportion to loudness. Sound levels, between 40 and 100 dB lasting 3 seconds, were presented at random from each of the four conditions. For each stimulus the subject faced the source of sound. In all, more than 1,400 separate loudness judgments were made when the barrier could be seen and the sound could be heard. As a control for our experiment, an additional 400 loudness judgments were made by 12 of these subjects while blindfolded.

The three barriers, constructed of acoustic tile, snow fence, or hemlock trees, with an identical sound source directly behind each one, as well as a source without any barrier, were arranged around a 15-foot radius circle. The barriers were about 3.7 m long and 1.5 m high. For the tile and hemlock barriers, sight of the source was completely obscured. The snow fence had a porosity of about 50 percent, so the source was only partially obscured, and, of course, for the no-barrier situation, the source was totally visible. Subjects were seated at the center in a swivel chair. The sound pressure level (SPL) was measured by a microphone centered about 15 cm above and facing towards the subject's head.

Geometric averages of the magnitude estimates of loudness and arithmetic averages of SPL (dB) were made for all subjects for each of the conditions. The blindfolded subjects, on the average, judged all conditions equally loud at the

Figure 2.—Averaged magnitude estimations of relative loudness vs. SPL (dB) for both tile and hemlock (solid line), slat fence (dashed line) and no barrier (dashed-dot line) situations.



same SPL. However, when the barriers could be seen, sizable differences in perceived loudness emerged (fig. 2). Although a given noise transmitted through hemlock (H) and tile (T) seemed equally loud, this same noise, surprisingly, seemed less loud when transmitted across an open unobstructed space (O) and even less loud when transmitted through the minimal snowfence barrier (F). That is, to maintain a given loudness for the listener, more sound energy was required at the listener for the F and O than for the H and T conditions. At the mid-range of stimulus levels, this difference was as much as 3.5 dB for the open and 7 dB for the fence.

These results were evaluated statistically by fitting a separate psychophysical function *(Marks 1974)* for each subject and taking the difference of their magnitude estimates for each condition at 70 dB SPL. All differences except T - H were significantly different from zero.

Visual shielding of the sound source dramatically affects the perception of sound transmitted through a barrier, but this effect is not related simply to shielding. As long as the source can be seen, reduced visibility is accompanied by a reduction in apparent loudness. However, when sight is completely obscured, this effect reverses, and the apparent loudness increases. This last result may (of course, many alternative explanations exist) hinge on people's expectation of a solid barrier's effectiveness. In that regard, it might be analogous to the well-known size-weight illusion, in which the weight feels heavier when it is compressed into a small volume *(Stevens and Rubin 1970)*. Based on experience, people generally expect that weight will increase with increasing volume, and thus the weight of massive object in a small container is often overestimated.

Perhaps this same kind of logic applies when a sound source is visually occluded by a barrier. Again, based on experience, people expect a solid barrier to reduce transmitted sound. Therefore, a given sound coming from behind a barrier seems surprisingly loud compared to one of the same level coming from a visible sound source and may, therefore, be overestimated. These results demonstrate a psychological effect of barriers on perceived loudness of as much as 7 dB. Unfortunately, the direction of this effect is not related simply to the visibility of the source. This certainly exemplifies the complex nature of the perception of environmental noise.

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Suburban Noise Control with Plant Materials and Solid Barriers

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ABSTRACT.—Studies were conducted in suburban settings with specially designed noise screens consisting of combinations of plant materials and solid barriers. The amount of reduction in sound level due to the presence of the plant materials and barriers is reported. Observations and conclusions for the measured phenomenae are offered, as well as tentative recommendations for the use of plant materials and solid barriers as noise screens.

YOUR $50,000 HOME IN THE SUBURBS may be the object of an invasion more insidious than termites, and fully as damaging. The culprit is noise, especially traffic noise; and although it will not structurally damage your house, it will cause value depreciation and discomfort for you. The recent expansion of our national highway systems, and the upgrading of arterial streets within the city, have caused widespread traffic-noise problems at residential properties. Blame for the problem rests with governmental bodies at all levels, and with real-estate developers and the general public in its demand for rapid automobile access and movement. Rather than attempting to fix the responsibility, however, our objective is to help reduce the suburban traffic-noise problem, using combinations of plant materials and solid barriers.

THE ALTERNATIVES

Preliminary planning that includes noise considerations, adequate zoning, and setbacks offers the greatest assurance of a relatively noise-free suburban environment. Where the noise problem already exists, however, means are available for reducing noise to an acceptable level.

Ideally, noise is controlled by reducing the source level. Lowered speed limits, relocated truck routes, and improved engine muffling can be helpful. An alternative solution is to create some sort of barrier between the noise source and the property to be protected. In the Twin Cities, for instance, wooden walls up to 16 feet tall have been built along Interstate Highways 35 and 94. Although not esthetically pleasing, they have effectively reduced traffic noise, and the response from property owners has been generally favorable.

Land forms consisting of earthen dikes, also known as acoustical berms, have shown promise. Roadside developments, strategically placed to take advantage of natural hills and other topographic features, reflect good planning to reduce noise from passing traffic.

Trees, shrubs, grass, and other plant materials can significantly reduce certain noises; and where conditions favor their use, no other means may be required.

HOW MUCH REDUCTION IS NEEDED

The amount of reduction in noise (attenuation) needed is determined by the level at the source and by requirements at the receiver. Source noise emitted by a large truck often exceeds 100 decibels (dBA) within a few feet of the vehicle. Requirements at the receiver vary considerably, depending on personal sensitivity, but most observers think that noise levels exceeding 70 dBA are objectionable for outdoor daytime activities, especially if conversation is to be maintained. (A reduction of 10 dBA means noise is cut about in half.) We favor levels in the 60- to 65-dBA range for daylight hours, and 50 to 55 dBA for evening hours, when background sounds are quieter. Our experience indicates that the majority of persons living adjacent to a 35-mile-per-hour arterial street do not object to noise levels in the 60- to 65-dBA range in their backyards.

To further illustrate the amount of reduction needed, consider a hypothetical situation in which the noise level of a large truck is 90 dBA at a point 10 meters from the center of the traffic lane. We would like to reduce the noise level to an acceptable 65 dBA at 30 meters from the same point. Some reduction occurs naturally with distance. Assuming a point source and spherical divergence, we would find the level at 30 meters to be about 80 dBA. The remaining 15-dBA reduction would have to come from some form of barrier interposed between source and receiver. However, neither a belt of tall dense trees, nor a solid wall of reasonable height, nor any combination of the two, will provide sufficient attenuation. Thus this situation represents a condition that can be remedied only by source-level reduction. It would therefore seem that heavy truck traffic, at its present high noise-emission level, should be excluded from suburban residential areas.

Consider a second illustration in which the noise level of an automobile is 75 dBA at a point 10 meters from the center of the traffic lane. The level at 30 meters is then only 65 dBA, which is acceptable to many persons for daytime outofdoor environments, although unsatisfactory for evening hours. We need only to reduce the level by as much as 5 to 10 dBA to provide a satisfactory acoustical environment in this case.

HOW MUCH REDUCTION IS POSSIBLE

With the means considered — plant materials and solid barriers — the amount of reduction possible depends largely on the height of the structure and the density and extent of the plant materials. Plant materials, by themselves, are capable of reducing noise levels as much as 8 dBA, and occasionally more. A tall masonry wall or earthen dike is capable of reducing noise levels by 15 dBA, when properly placed. However, practical considerations such as local ordinances, expense, and appearance rarely permit the construction of a solid barrier of sufficient height (12 to 20 feet) in residential areas.

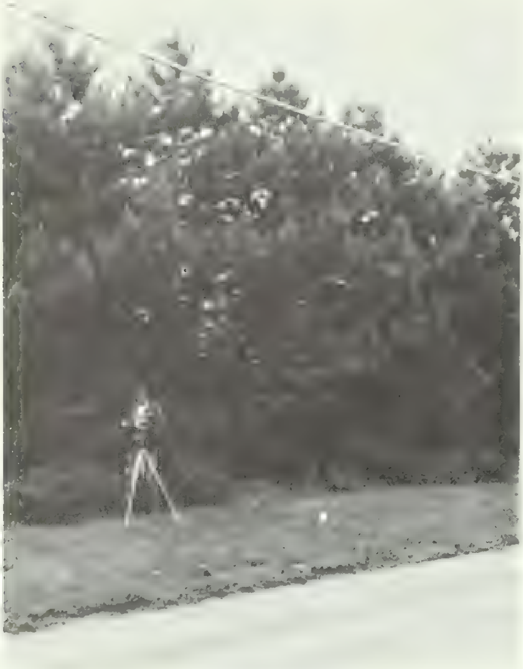
Our earlier studies in rural areas, where we used combinations of 12-foot-high solid earthen dikes and large dense trees, showed that reductions of 12 to 18 dBA are possible. Results of current experiments in suburban areas are not yet complete, but it appears that combinations of lower solid barriers and moderate-size plantings are also effective.

SITE SELECTION AND PROCEDURE

Ten residential properties in an upper-middle-class neighborhood were selected for study. Backyards of the properties faced a heavily traveled arterial street with a 35-mile-per-hour speed limit. Screen plantings and ground-surface configurations varied considerably from site to site. Three sites that illustrate the most significant features, for noise-control purposes, are described here (figs. 1, 2, and 3).

A sound-level meter was used to measure the noise of a vehicle as it passed by a test site, and a second meter was used to measure noise from the same vehicle as it passed by an open (control) area immediately thereafter. The difference in the two readings (attenuation) represented the amount of reduction that could be attributed to trees and shrubs, solid barriers, and ground-profile effect.

Figure 1.—Site 105 as viewed from the street. Low, dense, cotoneaster shrubs were backed by tall ponderosa pines.



The procedure was repeated at distances of 5, 10, 15, and 20 meters from the curb.

A special site, with relatively young trees on University of Nebraska property, was also selected to provide additional flexibility and control for the experiments. Here a power lawnmower was used as a noise source, and both microphone and source positions were varied. A concrete block wall (figs. 4 and 5), the height of which could be changed by adding courses, was also used in combination with the trees. One segment of the wall was placed in an open area, and an identical segment was placed within the tree belt.

Sound levels were measured by using three different barrier treatments and a control. In one case trees alone were located between the noise source and receiver; in a second case the wall alone was used; in the third both trees and wall were used. Source and receiver distances from the wall were varied from 5 to 20 meters. Readings were taken at various positions to determine the effects of wall, trees, and distance in reducing noise levels.

Figure 2.—Site 108 as viewed from the street: medium-height plantings, a woven board fence, and a downward-sloping ground profile from street to residence.

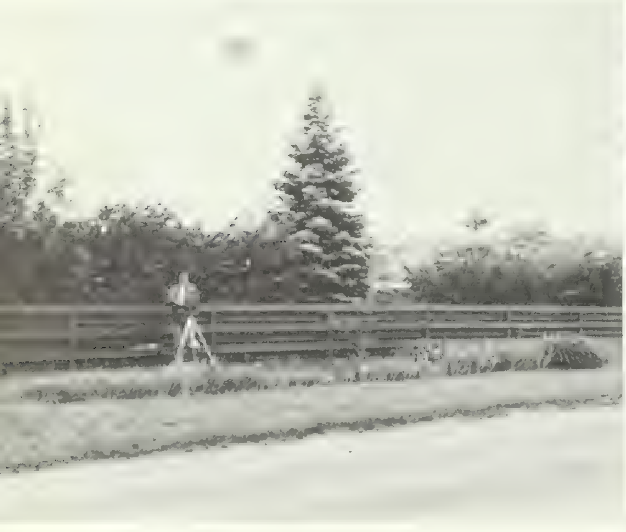


Figure 3.—Site 107 as viewed from the street: tall evergreens hide a 3- to 6-foot brick wall, and an upward-sloping ground profile from street to residence.

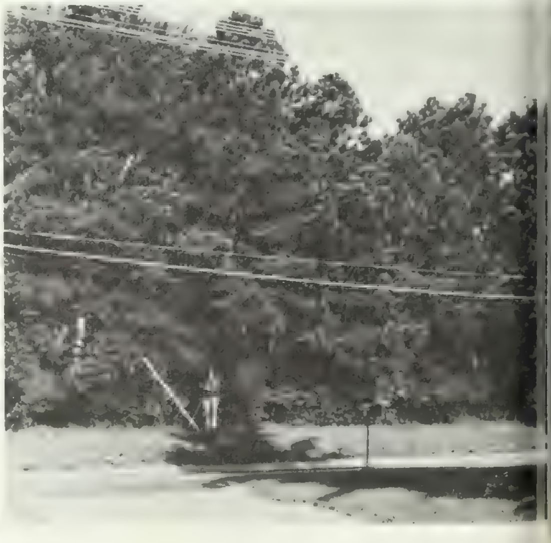
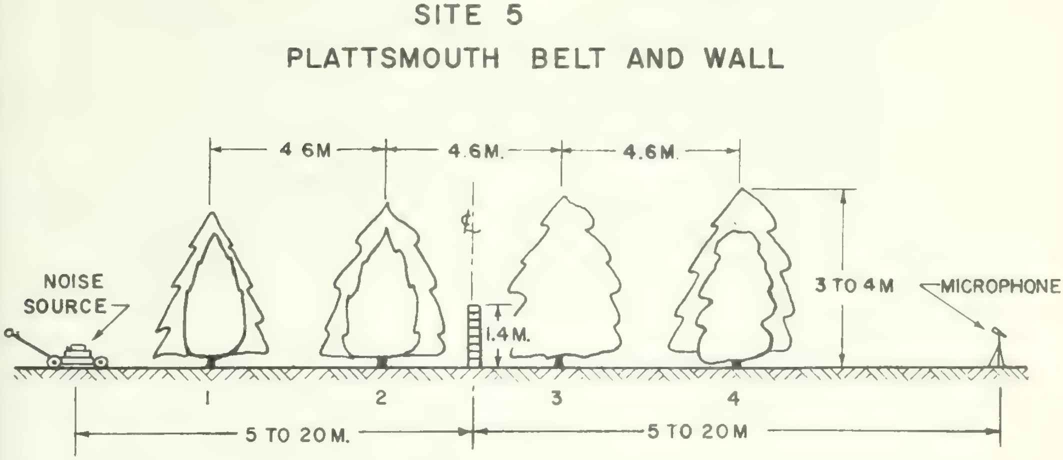


Figure 4.—Site III: Schematic diagram of wall within belts of trees.



ROW NO	NAME OF TREE
1	AUSTRIAN PINE ALTERNATED WITH ROCKY MT. JUNIPER
2	PONDEROSA PINE ALTERNATED WITH EASTERN REDCEDAR
3	SCOTCH PINE
4	AUSTRIAN PINE ALTERNATED WITH ORIENTAL ARBORVITAE

(TREE SPACING IN ALL ROWS — 2 M.)

Figure 5.—Site III: top, the sound-barrier wall; bottom, the belts of trees.

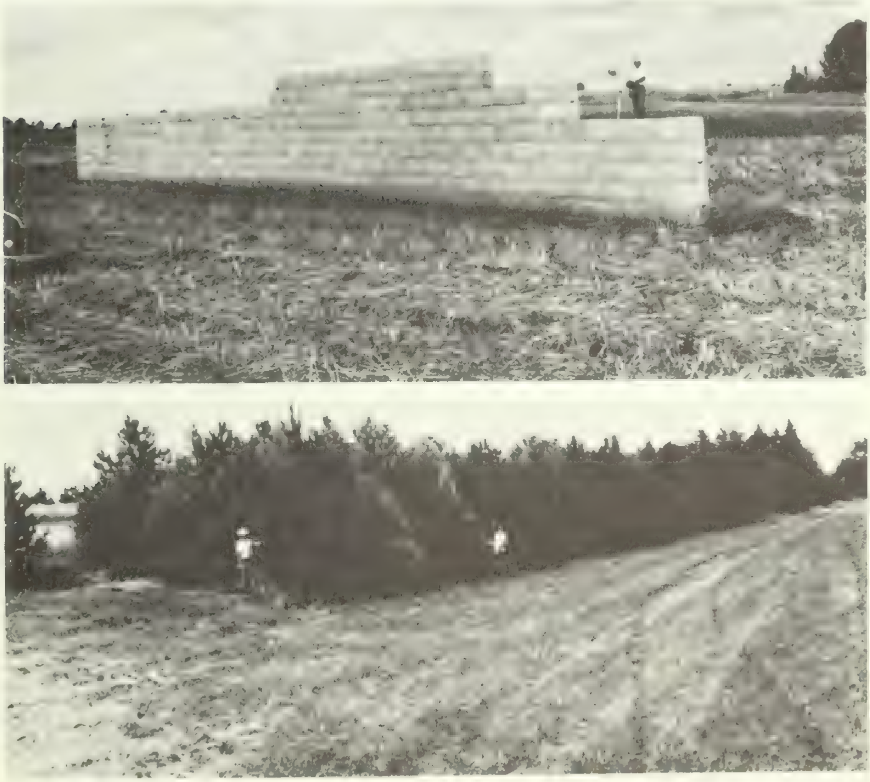


Figure 6.—Site 105: profile of site, noise level, and attenuation.

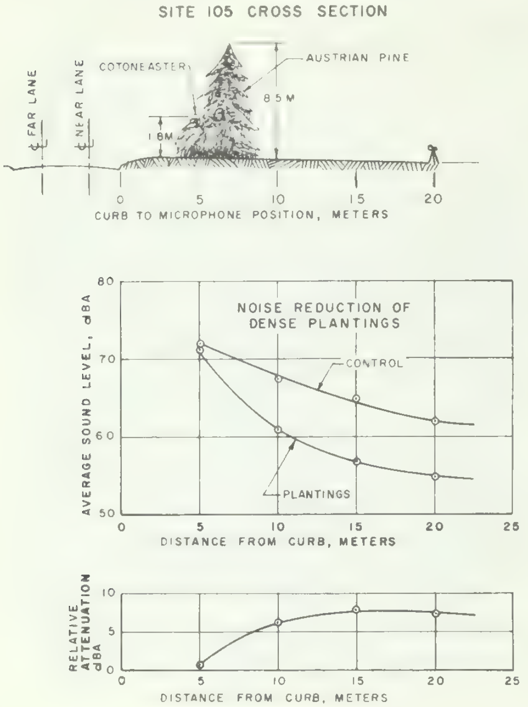


Figure 7.—Site 108: profile of site, noise level, and attenuation.

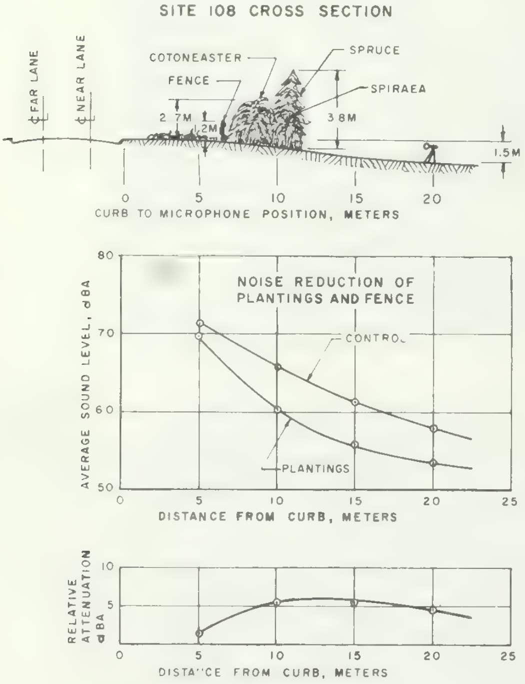
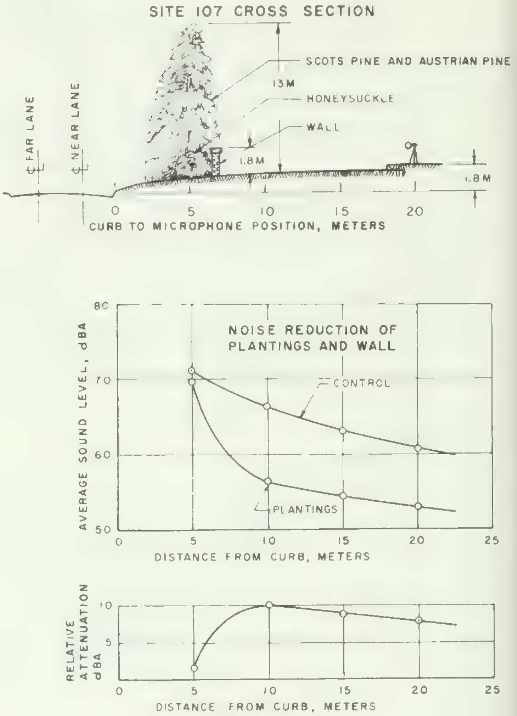


Figure 8.—Site 107: profile of site, noise level, and attenuation.



RESULTS OF EXPERIMENTS

Suburban Sites

Noise reduction characteristics of the three sites are shown graphically in figures 6, 7, and 8. Curves are positioned directly below the schematic cross-section drawings so the points denoting sound level and attenuation line up with the corresponding microphone positions. All readings are in dBA units.

Tree-Farm Site

Variation of sound level with distance and attenuation for the different surface treatments is shown in figure 9. The full height (1.6 meter) wall and the 10-meter wall-to-microphone distance were used in this instance.

The effect of different wall placements —between source and receiver—on the

Figure 9.—Sound level and attenuation with different surfaces.

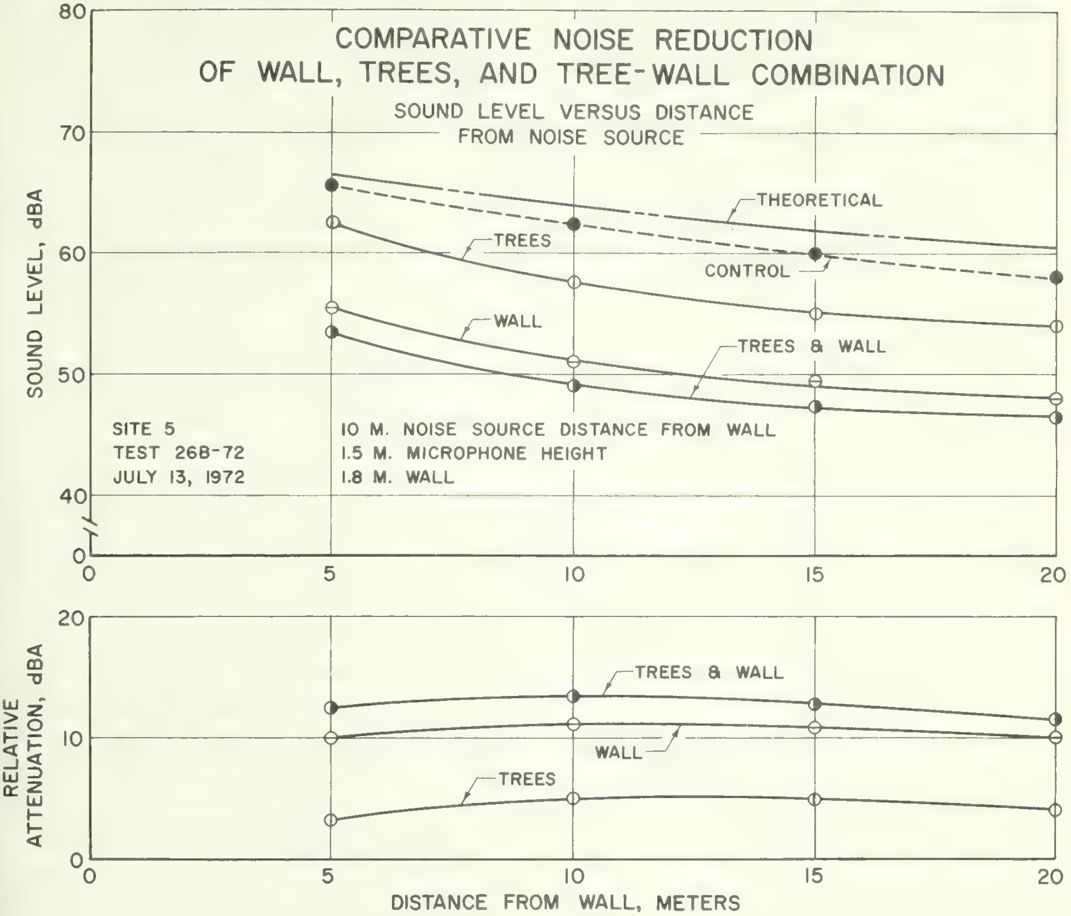


Figure 10.—Effect of wall placement.

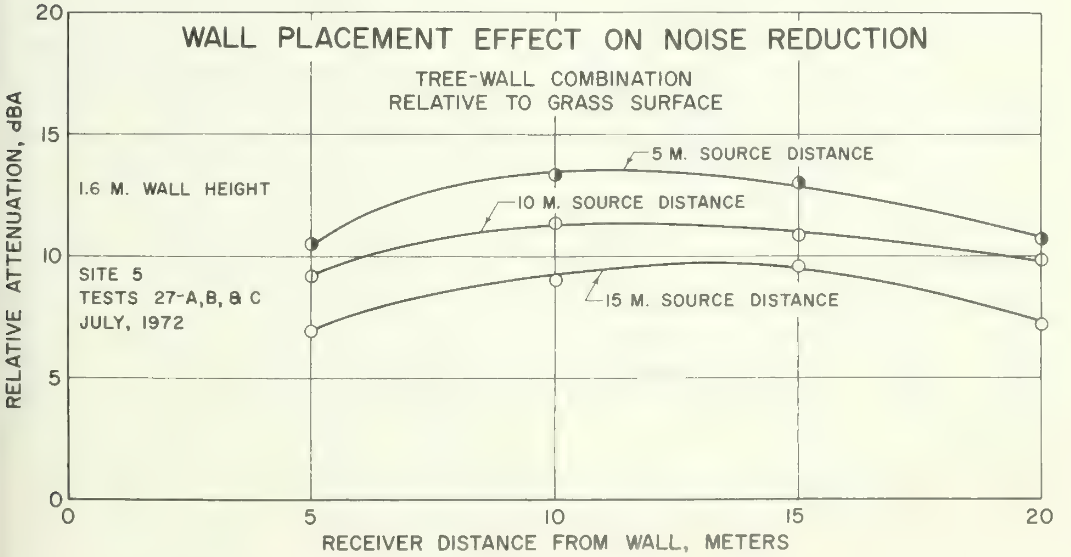
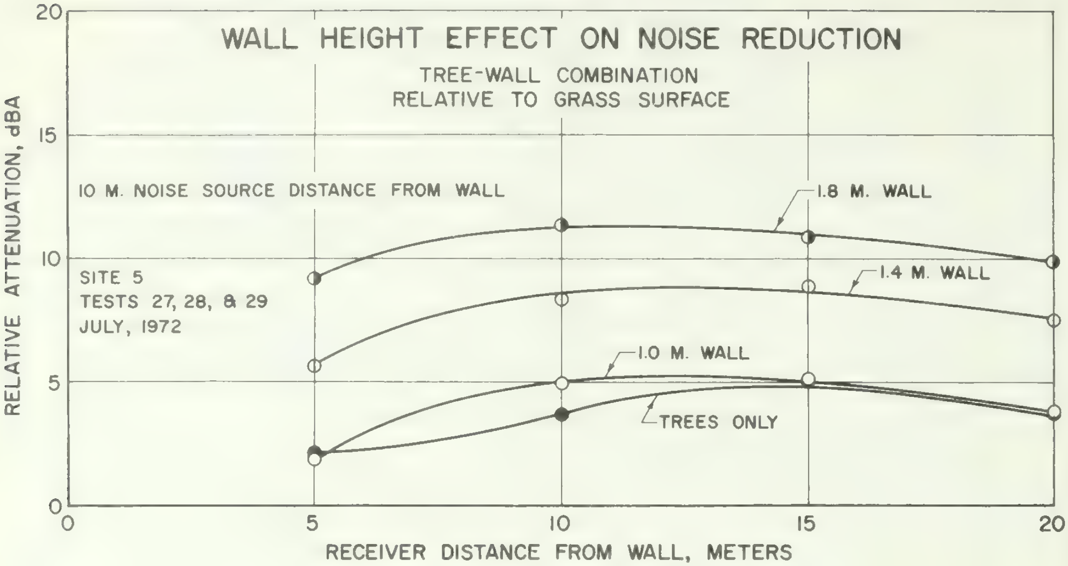


Figure 11.—Effect of wall height.



attenuation obtainable is shown in figure 10.

The effect of walls of different height combined with trees is illustrated in figure 11. A trees-only curve has been included for comparison.

OBSERVATIONS AND CONCLUSIONS

Results of the current series of suburban experiments are not fully analyzed at this time, and further experiments under controlled conditions are scheduled for next summer. Although our conclusions must be somewhat tentative, the general pattern of results is consistent and reliable.

At some of the sites, it appears that existing natural barriers, combined with additional plantings and some form of a low solid barrier, are adequate for the control of traffic noise from 35-mile-per-hour automobiles (figs. 6, 7, and 8). For similar suburban sites, continuous plantings of dense shrubs backed up by taller trees, as in the case of site 5 (figs. 1 and 6) are capable of providing sufficient protection from automobile and light truck traffic noise.

Where individuals are more sensitive to noise, or where the residence is rather close to the traffic lane, additional protection in the form of a higher solid barrier, such as an earthen dike, solid masonry wall, or tight wooden fence may be necessary.

It also appears that there is no practical means for reducing noise from large trucks to a level acceptable in suburban areas. The source itself must be brought under control.

RECOMMENDATIONS

1. To reduce noise from suburban automobiles and light trucks to an acceptable level where the residence is at least 25 meters from the centerline of the roadway, plant one or two continuous rows of dense shrubs as close to the curb as possible, and one or two continuous rows of dense trees behind the shrubs. One or both plantings should be of evergreens for year-round protection.
2. Where immediate relief from traffic noise is desired, erect an earthen dike, masonry wall, or solid wooden fence. The height should be sufficient to screen the noise source from view at the location to be protected. Landscaping should be included to provide

additional protection, when the trees become larger, and to decrease the reflection from the hard wall surface back across the street.

3. Where the residence is less than about 20 meters from the centerline of the roadway, both trees and a solid barrier are necessary.

Role of Land Use Planning in Noise Control

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This study was supported primarily by the Massachusetts Agricultural Experiment Station, University of Massachusetts (paper No. 1061), with additional support from the U.S. Department of Interior Office of Water Resources Research and the USDA Forest Service, Northeastern Forest Experiment Station, Pinchot Institute for Environmental Forestry Research.

ABSTRACT.—A method for controlling outdoor noise through land use planning is presented. The method utilizes a computer model that broadly assesses the likely noise environments of a community on the basis of generalized land use and highway noise production and transmission conditions. The method is designed to enable town planners and other community decision-makers to identify those general areas that are potentially unsuitable for noise-sensitive types of development such as housing. The method also predicts probably changes in noise environments and in the suitability of those environments due to general changes in land use (development). The method does not require site-specific measurements.

AS THE INTEREST of this conference in the acoustic environment indicates, noise pollution is one of the hazardous and disagreeable byproducts of human activity that warrants control. Historically, noise has been an undesirable feature of city life. Since World War II, however, it has become an undesirable feature of communities in general. The population explosion of recent decades and the subsequent process of decentralized development have brought increasingly large numbers of suburban as well as urban residents into objectionable proximity to proliferating sources of noise.

Insofar as the actual noise levels of offending sources in the environment are not likely to be reduced for some time, the abatement of noise pollution today depends largely on our ability to control noise in transmission. Controlling sound in transmission involves manipulating the effective proximity of a noise source and the noise-sensitive receiver. In the outdoor environment, this manipulation constitutes the role of land use planning in noise-pollution control.

Noise planning controls may operate at either of two scales. At a larger planning scale are general land use allocation noise controls. These are primarily allocations of various types of development within a larger landscape context (such as a town) to appropriate noise-environment zones. In other words, noise-sensitive land uses are allocated to quieter zones and noisier land uses are allocated to noisier zones. Noise control is for the most part a matter of isolating or aggregating land uses to prevent the undesirable exposure of noise-sensitive areas. At this scale, specific types of noise buffers between uses are not considered.

At a smaller planning scale are what might be called land use management noise controls. These include the provision or enhancement of various types of noise buffers between acoustically incompatible land uses. In other words, barriers, forests, fields, distances, and other buffers are maintained or managed between noisy land uses (factories, highways, shopping centers) and noise-sensitive land uses (neighborhoods, schools, hospitals). Generally at this scale, a particular noise problem is either controlled (for example, by constructing a berm between a housing development and a highway) or prevented (for example, by siting a school at a suitable distance from a factory).

To date, these opportunities for noise control through land use planning have not been presented in terms particularly useful to planners and other decision-makers. With the exception of a highway-noise-simulation model developed by the firm of Bolt Beranek and Newman *(Galloway et al. 1969)*, previous outdoor noise assessment techniques, notably "community noise reaction models" *(Great Britain Committee 1963, EPA 1972)*, have relied entirely on site-specific measurements. Such measurements are both time-consuming and costly and therefore highly impractical for many planning purposes. In addition, site measurements are really useful only in defining existing noise problems such as the extent to which noise from an airport affects the noise character of the surrounding landscape. Moreover, measurements require that each noise problem be evaluated separately on the basis of measurements pertaining only to that particular problem. In general, present noise models cannot be used practically to assess multiple noise problems. Nor can they be used to predict the probable effects of proposed noise intrusions (airports, industries, and shopping centers) on surrounding environments.

Planning, however, relies upon tools that are both practical and predictive; that is, assessment techniques and planning guidelines that can be used with relative ease to evaluate in a general way a wide variety of existing or potential landscape situations. The almost total lack of such tools for noise-related planning purposes has led to the research reported here. A computerized technique or methodology for controlling outdoor noise through land-use planning is discussed.

This technique is intended to provide a practical basis for larger scale noise-related land use planning. Specifically, our methodology is designed to enable planners and other decision-makers to broadly identify those areas of the landscape within a community context that are potentially unsuitable for noise-sensitive types of development (for example, housing). It is further designed to predict probable changes in noise environments and in the suitability of those environments due to general changes in uses of the landscape. The notable feature of the methodology is that it does not require site-specific measurements.

We have also developed a nonmeasurement technique to aid smaller scale noise-related land use-planning and management decisions *(Fabos and Caswell, 1977)*. However, this technique, which is designed to enable users to estimate and avoid (through buffering) potential noise conflicts between adjacent but different uses of the landscape, is not discussed here.

This noise-pollution planning technique was developed as part of a larger interdisciplinary research effort (ongoing at the University of Massachusetts) known as the Metropolitan Landscape Planning Model Project *(Fabos 1973)*. For a discussion of the nature and operation of the Metropolitan Landscape Planning Model, which deals with a variety of resource, hazard, and use-suitability aspects of the landscape, see the paper by Fabos and Ferris included in these proceedings.

THE NOISE ENVIRONMENT ASSESSMENT METHODOLOGY

Noise is a dynamic phenomenon that, once generated by a source, travels over a number of transmission paths to receivers located at various distances from the original point or area of noise output. The noise level at a given receiver therefore depends upon the original strength of the noise at the source and upon the degree of loss in this strength that is caused by the physical characteristics (trees, hills, pavement) of the transmission path along which the noise has traveled.

The present noise methodology is based on this acoustic principle. For any given community, procedures were developed for determining: (1) noise source areas and the likely strengths of these sources, (2) transmission loss areas and the likely degree of noise reduction provided by these areas, and (3) the probable noise environments that result from the transmission of noise from noise source areas through transmission-loss areas to other parts of the community.

The basis for these three procedures is described below. An exemplary application of the methodology to the Town of Burlington (located in the northwestern section of the Boston metropolitan region) for data relating to 1971 is used to illustrate each procedure.

Procedure for determining noise source areas

The procedure for determining noise source areas is based on two general types of noise sources that may appear in the landscape: (1) land uses and (2) highways.

Noise source areas were determined first by assigning a characteristic noise level to each land use and highway type, and second by aggregating those land uses and highways having similar noise levels into land use and highway noise groups (tables 1 and 2). The mapping of these groups for any town would

Table 1.—Assigned land use noise levels and resultant land use noise groups for land uses in the Town of Burlington in 1971

[A 1971 land use map aggregated according to these land use groups would yield a map showing the various land use noise source areas comprising the town for that year.]

Land uses in land use noise group	Assigned land use noise level
	dBA
Open space (wetland, forest, openland, abandoned land)	35
Farmland Orchard Nursery Cemetery Estate	40
Low-density housing	45
Medium-density housing; low-intensive recreation (golf course, driving range, drive-in)	50
Townhouse Garden apartment Public institution	55
Lighter industry	60
Shopping center Medium intensive recreation (playground, athletic field)	65
Strip commercial Intensive recreation (amusement park)	70
Core commercial Heavier industry	75
Mining (sand and gravel and traprock)	80

Table 2.—Estimated highway noise levels and resultant highway noise groups for secondary and primary roadways in the Town of Burlington in 1971

[Noise levels are based on near-peak to peak-hour conditions of road use. A 1971 road map (USGS toposheet), aggregated according to these highway groups, would yield a map showing the various highway noise sources comprising the town for that year. It should be noted that at the time of this mapping, the topography of the town would be used to make noise adjustments for steep roadway gradients.]

Highway (HW) characteristics	Noise level (listener location = 12.5')
	dBA
HW$_1$: 25 mph, 5-10 vehicles per mile; No % heavy trucks or buses; even flow; good road surface; shallow gradient	60
HW$_2$: 30 mph, 10-15 vpm; 2.5% heavy trucks or buses; even flow; good road surface; shallow gradient	65
HW$_3$: 35 mph, 20 vpm; 5% heavy trucks or buses; even flow; good road surface; shallow gradient	70
HW$_4$: 35 mph, 30 vpm; 5% heavy trucks or buses; even flow; good road surface; shallow gradient	72
HW$_5$: 35 mph, 30 vpm; 5% heavy trucks or buses; uneven flow; good road surface; shallow gradient	76
HW$_6$: 40 mph, 35 vpm; 10% heavy trucks or buses; even flow; good road surface; shallow gradient	
HW$_7$: 35 mph, 40 vpm; 10% heavy trucks or buses; uneven flow; good road surface; shallow gradient	79
HW$_8$: 50-55 mph, 60 vpm; 10% heavy trucks or buses; even flow; good road surface; shallow gradient	
HW$_9$: 60-65 mph, 90 vpm; 10% heavy trucks or buses, even flow; good road surface; shallow gradient	85

then yield the various noise source areas occurring within that town.

Land use noise levels were assigned on the basis of results of a recent outdoor noise-environment measurement survey undertaken by the State of California *(EPA 1972)*. Although the noise produced by a noise environment varies greatly over a 24-hour period, this survey statistically reduced the time-varying noise output of each measured environment to a single composite noise level in dB(A). (DB(A)'s are frequency-weighted decibels measured on an A-network sound-level meter.) In cases where the surveyed environment was a single-use environment comparable to a land use type, the measured statistical noise level was assumed to be a valid expression of the noise generally associated with that land use type. The noise levels of land use types not specifically sampled by the measurement survey were estimated on the basis of the similarity of their noise-producing characteristics to one or another of the measured environments.

Highway noise levels were assigned according to the highway noise simulation model developed by Bolt, Beranek, and Newman *(Galloway et al. 1969)*. This model estimates the noise level in dB(A) of any highway on the basis of the typical noise contributions of its road and traffic characteristics. These include vehicular density (in vehicles

Table 3.—Transmission loss groups and figures based on dominant land use characteristics for land uses in Burlington in 1971

[A 1971 land use map aggregated according to these groups would yield a map showing the transmission loss areas comprising the town for that year. Transmission loss figures are given in decibels per thousand feet (dB/1000′) or decibels per doubling of distance (dB/dd), depending upon which rate of noise reduction is more appropriate for the predominant landscape characteristic.]

Dominant physical characteristic	Land uses in transmission loss group	Transmission loss figure	
		dB/1000′	*dB/dd*
Wet land	Wet land	—	1.0
Grass/low vegetation	Farmland, open land, golf course, playground, cemetery, athletic field	—	3.0
Trees (less than 30% crown closure)	Orchard, nursery, abandoned land, estate	—	4.0
Trees (30-80% crown closure)	Forest	—	4.5
Trees (greater than 80% crown closure)	Very dense forest	—	5.0
Hard ground/pavement	Amusement park, drive-in	1.0	—
1-2 story structures (scattered)	Low-density housing	3.0	—
1-2 story structures (less scattered)	Medium-density housing	5.0	—
1-2 story structures (very large)	Shopping center, strip commercial, heavy industry	6.0	—
2+ story structures	Townhouse, garden apartment, light industry, public institution, core commercial	10.0	—
Land form	Sand and gravel, traprock mining	8.0	—
Water	Open water	0.0	—

per mile), vehicular speed (in miles per hour), traffic composition, traffic flow, road surface, road gradient, and listener location.

Procedure for determining transmission loss areas

The procedure for determining transmission loss areas is similar to that used for determining land use noise source areas. Transmission loss areas were determined first by grouping land use types according to the similarity of their dominant physical characteristics (pavement, grass, trees, one-story buildings, etc.), and second by assigning to each group a figure of transmission loss that reflected in a very general way the rate of noise reduction provided by that group's dominant physical characteristic (table 3). The mapping of these groups for any town would then yield the various transmission loss areas occurring within that town.

Transmission loss figures were extrapolated wherever possible from the results of previous studies concerned with the transmission of noise in the outdoor environment *(Simonson 1955, Embleton 1963, Winterbottom 1965, Sexton 1969, Robinette 1972, Aylor 1971 and 1972)*. They are, however, only very general estimates of average landscape transmission loss and do not account for noise reductions due to air, temperature, wind, or possible differences in terrain.

Procedure for calculating noise environments

A computer model was developed to compute the various noise environments that would result when noise from source areas traveled through transmission loss areas to other parts of the town. The model assumes that each noise source area mapped for a town can be represented as an aggregate of smaller individual noise sources or sourcelets distributed either within that area (in the case of land use noise sources) or along the length of that area (in the case of highway noise sources).

To establish a basic acoustical relationship between the noise level corresponding (assigned) to a noise source area and the noise strengths of the sourcelets necessary to produce that noise level, the model further assumes that the noise strengths of sourcelets comprising a land use noise source area are such that, if the entire mapped region were composed of the same sourcelet strengths and the same rate of transmission loss, the noise level corresponding to that land use source area would result. Analogously, the model assumes that the noise strengths of sourcelets along a highway noise source are such that, if the highway were straight, the noise level corresponding to that highway source would result.

Input to the computer model includes sets of digitized data corresponding to numerous points (sourcelets) on the noise source and transmission loss maps. These digitized points serve to locate on an x-y coordinate system the sourcelets distributed within each land use noise source area and transmission loss area and along each highway noise source area mapped for a town. The sets of digitized data corresponding to each map are then successively manipulated by four computer programs run in a prescribed sequence.

The final printout is a spatial display of originally digitized points. At each point, the "new" noise level resulting from the transmission of sourcelet noise through the landscape is given in symbolic form. The computation of these new noise levels includes the effects of spatial attenuation — the natural reduction in noise due to spherical spreading as noise travels away from a source.

Each symbol on the final printout represents a 10-dB(A) range of noise levels. By manually tracing a line along the interface of different printed symbols and by converting these symbols to the noise-level ranges they represent, a noise map is produced. This map illustrates what are in effect the various general noise environments of the region represented by the original noise source and transmission loss map (fig. 1).

Utility of the noise map

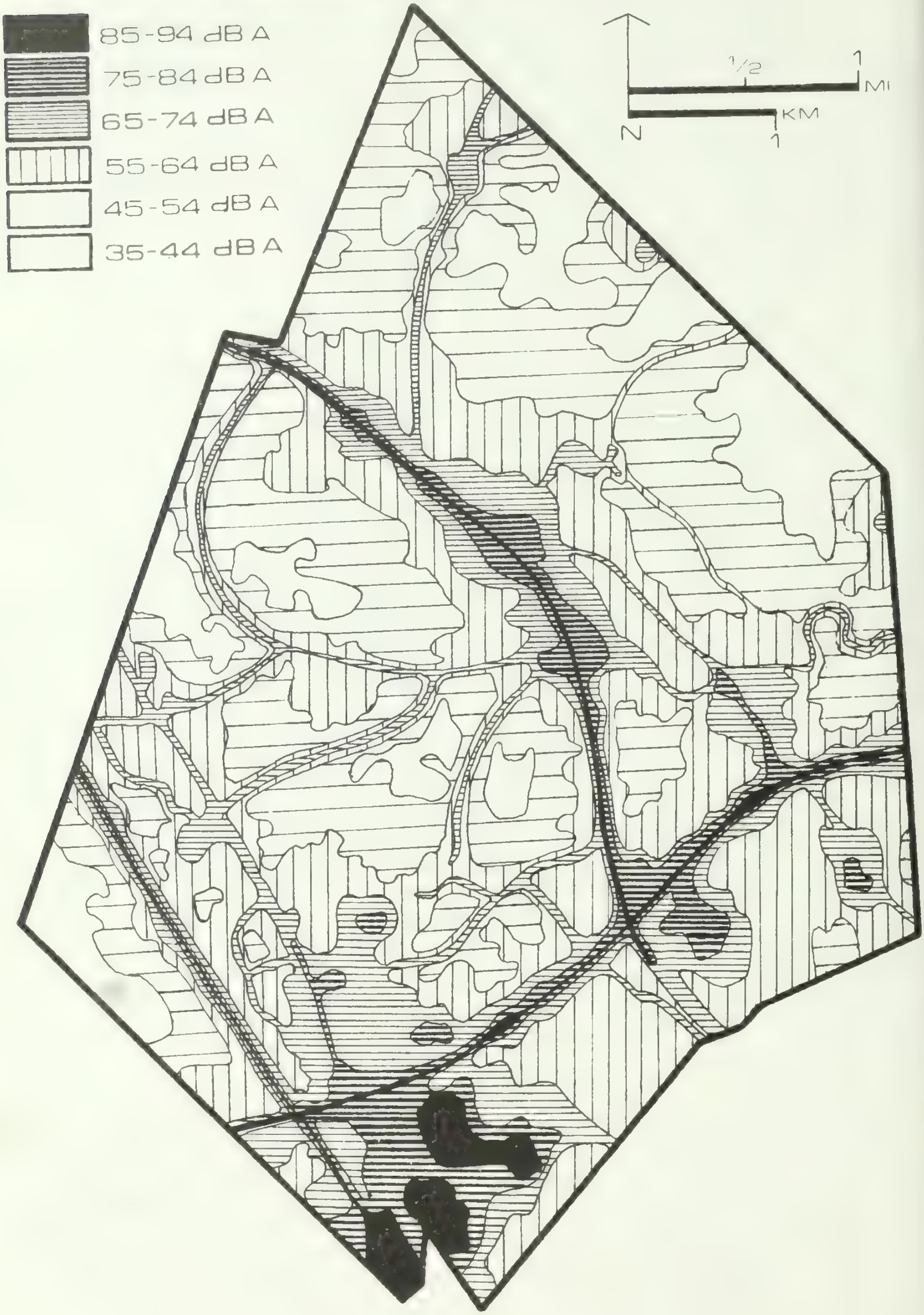
With the noise map, a planner or other decision-maker is for the first time provided with the information necessary to carry out planning policies that reflect the potential noise suitability of different parts of a town for different types of development.

For example, a planner might decide that it is desirable to restrict all future noise-producing landscape uses such as airports, shopping centers, and certain industries to already noisy areas. The noise map of the town shows where these existing noisier environments are. Alternatively, the planner might decide to set aside quite areas of the town for the location of proposed noise-sensitive uses such as low-density housing, hospitals, schools, and libraries. Again, the noise map of the town shows where these quieter environments are.

In his approach to these noise control planning decisions, the planner may be as specific or as general as the noise map allows. On one hand, he may establish detailed development policies for each of the different noise environments appearing on a noise map. On the other hand, he may choose to group several noise environments into a few major noise categories, which generally summarize his noise planning objectives for the town.

A review of pertinent literature indicates that there are two views or concepts of environmental noise pollution

Figure 1.—The 1971 noise map produced by computer for the Town of Burlington, Massachusetts. The map is based on the noise interaction among land use and highway noise source areas and transmission loss areas occurring in the town in 1971.



that might be used to provide a basis for a more specific approach to noise control planning and decision-making.

The first view or planning concept is based on noise-complaint history and urban noise-annoyance surveys *(Great Britain Committee 1963, EPA 1972).* This view suggests that all acoustically different uses of the landscape are to varying degrees incompatible and so should not occur adjacent to one another without some buffering. In other words, the various noise environments on a noise map would be to some extent degraded if land uses or highways having noise levels (tables 1 and 2) above 10-decibel noise level ranges were allocated to those environments. The greater the difference between the noise level of the proposd use and the noise-level range typical of the existing environment, the greater the loss in noise quality to the affected part of that environment, assuming no noise buffering landscape devices (trees, hills, berms, etc.) are already present or are intended to be used.

The second view or planning concept is based on people's reactions to aircraft noise *(Kryter 1968).* This view suggests that intrusive outdoor noise constitutes no perceivable impact when below a basic annoyance threshold of about 55 dB(A). In other words, the introduction of a use having a typical noise level of 55 dB(A) or less would not be expected to negatively affect the noise quality of any noise environment appearing on a noise map, even if the environment in question were substantially quieter than the proposed use.

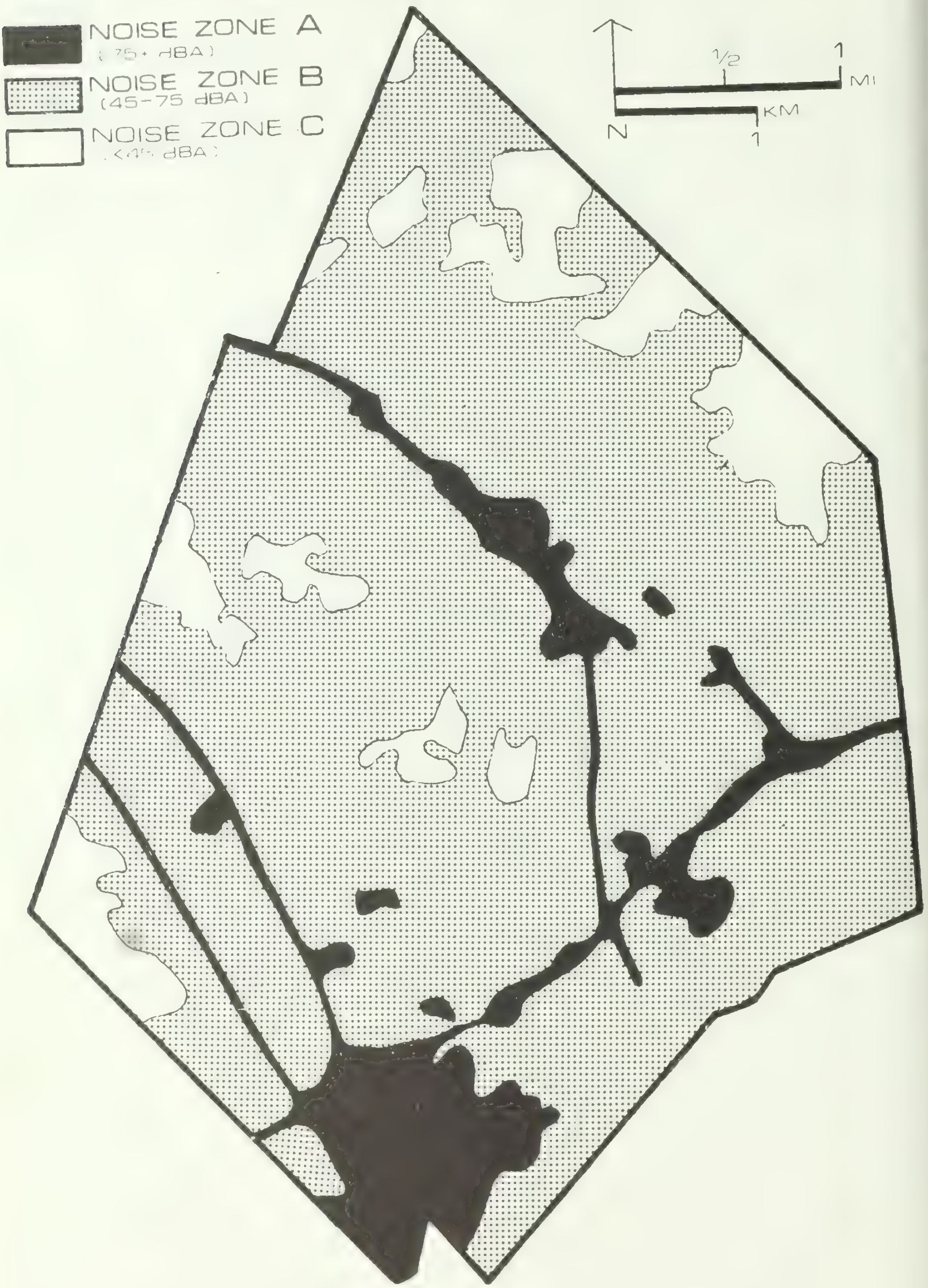
According to the first of these noise control planning concepts, a town planner may reasonably establish a development policy whereby only uses that are as quiet as or quieter than an existing noise-map environment may be introduced into that environment unless special measures are taken. Alternatively, according to the second planning concept, the planner may reasonably establish a similar but less stringent (and perhaps less ideal) development policy affecting only those proposed uses whose typical noise levels exceed 55 dB(A). Either way, the point is that the planner is enabled by spatial information in the form of a noise map to formulate specific noise pollution prevention policies and plans for all sectors of his community.

A more general approach to noise control planning and decision-making would be to use the noise map in a somewhat different way. A practical example of this type of approach might be as follows.

On the basis of the range of noise environments that may occur on a noise map, the planner identifies three general zones — A, B, and C — to summarize his noise-planning objectives for the community. Zone A would include those noise environments that are potentially hazardous or unsafe in terms of people's hearing. It has recently been established that an exposure of several hours to noise levels of about 75 dB(A) on a daily basis results in some degree of permanent hearing loss in most people *(EPA 1972).* Zone A would therefore be composed of noise environments having general noise levels of 75 dB (A) or more. These are areas of the landscape that are potentially unsuitable for residential and other noise-sensitive types of development unless buffers of some kind are provided. As a general rule, the planner would restrict zone A landscapes to noisier commercial, industrial, and recreational activities.

Zone B would include those noise environments that are potentially annoying to people residing in them. Some noise-annoyance studies suggest that the first signs of annoyance in persons living in quiet low-density residential neighborhoods are produced by noise levels exceeding 45 dB(A) *(Great Britain Committee 1963, EPA 1972).* Other studies suggest that annoyance in sensitive (quiet) community areas begins only with noise levels exceeding

Figure 2.—The 1971 noise map for the Town of Burlington aggregated according to three noise-level zones. (It should be noted that had the B zone begun at 55 dBA rather than 45 dBA as shown, the area represented by the zone would have been considerably smaller.)



55 dB(A) *(Kryter 1968)*. Depending on the planner, zone B would therefore be composed of noise environments having general noise levels between 45 or 55 dB(A) and 75 dB(A). These are areas of the landscape that are probably suitable but not always ideal for a range of development types. In general, the planner would allocate higher density housing, industrial parks, recreation uses such as golf courses, and the like to zone B landscapes. The decision to allocate quieter uses to B zones would reflect the overriding quality of other physical and cultural aspects of the landscape.

Finally, zone C would include the remaining noise environments, those that are neither potentially hazardous nor potentially annoying. These are areas of the landscape that are entirely suitable for all types of development. Insofar as possible, the planner would reserve zone C for activities that would not degrade the existing noise environment.

In cases where a planner is interested in assessing a town from several environmental standpoints in addition to that of noise (for example, potential air pollution, flooding, water supply, sand and gravel supply, etc.), the A-B-C noise-zone map that results from this summarization of a noise map may be of even greater planning use than the more detailed noise map from which it is derived (fig. 2).

DISCUSSION

There are three basic features of the noise enviroment assessment methodology that recommend it as a technique for larger scale noise-related land use planning.

First, it requires no measurements and so is practical to use. The only source information required is a land use map and a U.S.G.S. quadrant map or other roadway/topography map (corrected for highway noise characteristics) of the town to be assessed. Although a certain amount of traffic-data collection and digitizing is required, the time/cost involved is small compared to that of multiple on-site measurements and measurement analyses.

Second, the methodology is designed to operate at the community scale. The noise environments comprising an entire community or even a group of communities can therefore be assessed at once. This provides a useful overview of the noise situation and a context for subsequent decision-making.

And third, the effects of any proposed change in land use/highway development on the surrounding noise landscape (changes in noise environments) can be predicted simply by redigitizing the points on the land use or highway noise source maps and the transmission loss may where the change is to occur. Rerunning the program sequence yields a new noise map. In this way, the noise consequences of any land use allocation decision (and its alternatives) can be evaluated before changes in the landscape are actually made.

Each of these features makes the methodology a useful tool for landscape planning and therefore a useful method of noise pollution control. However, as the first noise-environment simulation technique of its kind, the methodology understandably exhibits one apparently significant limitation: it lacks the accuracy provided by site-specific measurements.

Unfortunately, the noise-producing and transmitting characteristics of the landscape do not often easily lend themselves to generalization. For this reason, we have sometimes been forced in our methodology to make assumptions about the noise landscape that do not necessarily represent reality. This is especially true of the assignment of transmission loss values and certain land use noise levels.

The issue of accuracy as a methodological limitation, however, must be considered in light of two important facts. In the first place, as acousticians acquire more land use noise data and better expressions of transmission loss, these can be easily incorporated into the present assessment procedure.

In the second place, the noise methodology is not designed for smaller scale land use allocation/management purposes. Although better base data are always desirable, the likely noise environments now illustrated by the computer-generated noise map are in all probability quite suitable for the level of decision-making that they are intended to influence.

CONCLUSION

We believe that our environmental noise assessment methodology provides a much-needed basis for large scale land use-related noise pollution evaluation and prevention. We recognize, however, that in the absence of standard noise-environment modelling procedures, numerous assumptions and generalizations were made about the relationship between the production/transmission of noise and certain characteristics of the physical landscape, primarily land use. With the exception of highway noise simulation, no precedent exists for making such generalizations. Those made here represent what is in effect a professional interpretation of available site-specific (measured) noise production and attenuation data. The validity of the assessment methodology is therefore based largely on analogies and inferences made from empirical noise-related research.

This approach to noise tends to be problematic from several points of view. First, the nature of generated and transmitting noise in the outdoor environment is often highly variable. Although various examples of some types of land uses, such as low- and medium-density housing, can be reasonably said to contribute on the average a similar amount of noise to the environment, various examples of other land use types, such as industry, may be responsible for very different amounts of noise output. For example, the difference in the outdoor noise levels generated by a plastics factory and a paper mill may be substantial. Generalizing about the noise output of a land use typed "industry" is therefore likely to underestimate the noise contributions of some industrial land uses while overestimating the noise contributions of other industrial land uses.

The variability in transmitting noise is even more of a problem. Noise in transmission is complexly affected not only by all the elements of the landscape with which it comes in contact, but also by the arrangement of those elements, that is their location and orientation with respect to the noise source area. Furthermore, the degree to which noise is affected by the landscape depends upon the kind of noise that is generated (its predominant frequencies) as well as the areal extent of the source itself. To estimate the effect of a land use noise source on a receiver located some distance away is therefore far from simple.

Second, the body of data pertaining to those aspects of the outdoor noise environment (particularly noise in transmission) which are of interest in noise pollution control is not large. Since generalizations better approximate reality when drawn from numerous observed results, especially where the observed phenomenon is as complex as is noise, this is a fundamental problem.

Third, the lack of pertinent noise data is compounded by the fact that the comparability among investigated situations is low. Different measuring instruments are often used. Different source and receiver conditions are often sampled under still different landscape conditions. Even observed results are sometimes expressed in terms that to the non-engineer appear to bear little resemblance to one another. Drawing generalizations that can be applied easily to the problem of outdoor noise pollution control is made difficult by these experimental differences.

Finally, among the somewhat comparable noise experiments that have been undertaken, results are at times conflicting. For example, measured reductions of point-source noise in forests range from as little as 1.0 dB/100 feet of vegetation to as much as 7.0 dB/100 feet of vegetation *(Smith 1970)*. Until such experimental discrepancies are explained and resolved, attempts to apply empirical noise data must always be rather frustrating.

Despite these problems, it is felt that the approach taken in formulating the assessment technique presented here is entirely appropriate for and necessary to larger scale noise control planning purposes. In fact, if understood as a preliminary effort to translate observed acoustical data into a usable form for planners and others whose decisions influence the noise environment, we believe our methodology is an extremely valuable noise-planning tool even as it now stands. Without question, however, more empirical noise data and better expressions of landscape noise characteristics are needed, particlularly as regards (1) the noise-producing tendencies of acoustically complex and highly variable land use types such as industry and (2) all aspects of noise in transmission through the landscape. With more observed and comparable results, more representative generalizations about those results can be made.

Greater interaction between planners and accoustical engineers/scientists is therefore warranted. The apparent lack of communication between these professionals to date is responsible for many of the problems described above and encountered in our research. If noise pollution is to be practically controlled in the forseeable future, it is the responsibility of planners to articulate their noise-information needs, while it is the responsibility of acoustical scientists to generate the necessary information and translate it into understandable and easily applied terms.

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ENVIRONMENT AND PHYSICS OF METROPOLITAN AIR QUALITY

A First-approximation Urban-air-quality Indicator

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ABSTRACT.—Development of the first-approximation-urban-air-quality indicator was reported by the Economic Council of Canada. The indicator takes account of ambient concentrations of five pollutants: sulfur dioxide, particulate matter, oxides of nitrogen, carbon monoxide, and total oxidants. Epidemiological evidence indicating the potential impact of these pollutants on human health is also reported. Values of the indicator are calculated for the years 1971-74 for a number of Canadian cities: the overall trend appears to be toward cleaner air, though concentrations of oxidants and nitrogen oxides have increased.

THE CHARACTER OF URBAN CENTERS

DESPITE THE HUMAN TENDENCY to build urban islands of man-made physical environments, our cities are highly dependent upon their interaction with natural ecosystems. In days gone by, cities have always tended to be built in the most productive areas within natural ecosystems. By replacing plant and animal life with asphalt and concrete, houses and factories, and the products and residuals of production and consumption, man has created deserts in which there is minimal natural energy production and maximum human energy use. To fill this gap in net energy requirements, the city spreads its tentacles throughout the ecosystem.

The interaction between the energy-deficient man-made environment and the energy-surplus natural environment is dynamic, and the interface (the "urban confrontation") is often abrupt. The flow of energy and natural resources into the man-made centers and the outflow of man-made products, services, and residuals is continuous, causing a shift in costs and benefits across the interfaces. However, this area of urban confrontation is sufficiently distinct to describe the walls that encase the "fragile bubble-world" referred to by Mowat:

> "When, and if, man comes to regard himself as being in effect an alien entity in the ancient world that formed him, then he will have become the ultimate egomaniac, imprisoned in an infinitely fragile bubble-world of his own contriving — and unquestionably doomed."
>
> Farley Mowat, *Tundra,*
> McClelland and Stewart, Ltd.,
> Toronto, 1973, p. 13.

Unfortunately, the degree to which human activity affects the remaining elements of the natural environment that exist within cities is still difficult to define and, therefore, to include in the derivation of an urban environmental quality indicator.

The human population itself is exposed, at least to some extent, to pollutants that it generates; and if we assume that urban populations are (statistically) normally distributed with respect to susceptibility to environmental contaminants, we can see that the population potentially at risk serves as a convenient common weighting factor for aggregating the social impacts of environmental pollutants across urban areas (even though we are aware that air quality can differ greatly from point to point within each area). Because contaminated water can be avoided or rendered safe before use and because North Americans are protected against pollutants that may affect their food (by way of public controls and the availability of a great variety of food stuffs and food sources), the element of environmental pollution most critical to human health is the quality of air that urban populations must breathe. For these reasons the Economic Council of Canada developed its first environmental quality indicator in consideration of urban air quality.

DIMENSIONS OF AIR QUALITY

The popular perception of air pollution is that, if you can see it or smell it, it's "bad." This is, of course, a gross oversimplification: some pollutants, such as carbon monoxide or lead, may be completely undetected by the human senses at typical ambient concentrations. On the other hand, preoccupation with the multitude of elements and compounds that may pose a threat to human life in isolated instances may obscure general trends in air quality.

In constructing our first-approximation-air-quality indicator, the choice of which pollutants to include was largely pragmatic. That is, we included all the pollutants that are measured on a roughly consistent basis in most large urban areas in Canada. These are sulfur dioxide, nitrogen oxides, total oxidants, particulate matter, and carbon monoxide. A sixth pollutant group, total hydrocarbons, was rejected because of imprecise measurement and the absence of generally accepted criteria of safe ambient concentrations.

To provide guidance in our choice of pollutants to be included in the indicator, and also to confirm the choice of pollutant weights (relative severity factors), we undertook a statistical analysis of the relationship between air pollution and health. Weekly average ambient concentrations of the six pollutants mentioned above were related to hospital admissions among the most sensitive members of the population (those under 15 or over 45) for five categories of respiratory disease. In addition, a temperature variable was used to control for seasonal variations. Data were available for the last 41 weeks of 1972 for the cities of Windsor, Ontario, and Edmonton, Alberta.

Hypothesizing a simple linear relationship, we fitted regression equations for each category of respiratory disease by the technique of ordinary least squares. The coefficients, t-statistics, and coefficients of multiple determination (R^{-2}) for selected equations are shown in table 1.

The results, in summary, imply that, indeed, oxidants at levels found in ambient air in several Canadian cities are significant contributors to hospitalization for, in particular, upper respiratory ailments but other categories of respiratory ailments as well; this despite the general Canadian perception that conditions such as those found in Los Angeles are far removed from Canadian circumstances. Likewise, for Windsor, nitrogen oxides and, to some extent, sulfur dioxide air pollutants have some significant bearing on the respiratory well-being of individuals. And the results from our investigation of hospitalization in a third city, Sudbury, Ontario,

Table 1.—Selected regression results

Item	Independent Variables							
	SO_2	COH	NO_x	TOX	HC	CO	TEMP	R^2
WINDSOR, ONT.:								
Upper respiratory Infections	.2	—.5	1.6	2.3	—.3	—2.2	—.2	.42
	(.2)	(—.4)	(1.4)	(1.1)	(—.9)	(—2.0)	(—1.2)	
			2.6	4.0			—.3	.39
			(2.5)	(2.4)			(4.3)	
Pneumonia	1.6	—.1	1.2	1.7	—.4	—1.7	—.1	.37
	(2.2)	(—.1)	(1.1)	(.8)	(—1.3)	(—1.6)	(—.5)	
			2.2	3.4			—.2	.24
			(2.1)	(2.0)			(—2.9)	
EDMONTON, ALTA.:								
Upper respiratory Infections		12.6	40.5	8.3		—4.0	—.1	.22
		(.7)	(.5)	(3.4)		(—.9)	(—1.3)	
				8.9			—.1	.26
				(3.9)			(—1.7)	

Values in brackets are T-statistics.

Table 2.—Correlation coefficients, Windsor, 1972

Item	SO_2	COH	NO_x	TOX	HC	CO	Temp
SO_2	1.0	—	—	—	—	—	—
COH	.42	1.0	—	—	—	—	—
NO_x	—.01	.05	1.0	—	—	—	—
TOX	—.17	.00	.13	1.0	—	—	—
HC	.23	.39	—.40	—.51	1.0	—	—
CO	—.11	—.30	—.11	.38	.01	1.0	—
TEMP	—.39	—.55	—.01	—.10	—.34	.80	1.0

indicate that sulfur dioxide and particulate matter, alone or combined, do not provide a sufficient proxy indicator for all airborne pollutants in that hospitalization for respiratory ailments are not significantly explained by the occurrences of these pollutants. In all, this epidemiological examination lends support to the contention that the traditional concern (sulfur dioxide and particulate matter) must be extended to a wider array of pollutants; an indicator based on several pollutants is not a sufficient proxy for the general quality of urban air. Since, moreover, there are many costs to air pollution other than hospitalization for respiratory ailments, we also reject an air-quality proxy indicator based merely on oxidants, nitrogen oxides, and sulfur dioxide.

Simple correlation coefficients among pollutants (table 2) provide further statistical evidence that the five pollutants included in the indicator cannot be reduced further by using one variable as a proxy for one or more others: only one of these coefficients is as high as 0.5 (although two related to the correlation between pollutants and temperature are also higher than 0.5).

In addition, the literature on the health effects of air pollution provides numerous references to the increased impacts (synergism) that can be expected when two or more air pollutants occur simultaneously; there are, in addition, a few references to decreased impacts. The most notable evidence suggests that particulate matter (particularly small, respirable-sized particles), together with sulfur dioxide, may have an impact greater than the combined impact of both pollutant groups considered separately. Similarly, some experts treat ozone (oxidants) as a synergistic effect of the presence of nitrogen oxides and hydrocarbons together with sunlight; we have included ozone (oxidants) as a pollutant in its own right although we realize that emissions of the two precursors provide the only policy options for control purposes.

RELATIVE SEVERITY FACTORS

From medical evidence, and from our own epidemiological study, it is clear that, at the same concentration, different pollutants give rise to impacts of differing severity. To take account of this rather obvious fact, the concentration of each pollutant is weighted by a "relative-severity factor."

The relative-severity factor for each pollutant is based on the 24-hour average criterion established by the Ontario Ministry of the Environment, this criterion being the only common time base for which criteria are stated for all five pollutants.

The severity factors are in inverse proportion to the 24-hour criteria; hence total oxidants have the lowest acceptable concentration — 0.03 parts per million — and therefore have the highest relative severity factor —267. Table 3 shows the Ontario criteria and the severity factor for the five pollutants. Note that the scale of the factors is set by arbitrarily denoting the factor for carbon monoxide as equal to one. Finally, since the criteria indicate that one COH has eight times the impact of one part per million of carbon monoxide, the severity factor was determined accordingly without regard for the difference in units of measurement.

CALCULATING THE INDICATOR

The air-quality indicator for any one urban area is a weighted sum of the annual average 24-hour concentrations of the five pollutants and a synergism factor (to be discussed shortly). The annual mean concentration is multiplied by the relevant severity factor; the products are labelled "impact units per capita," and they can be added to yield a "city-pollution index." These calculations are depicted schematically in figure 1.

The synergistic impact of sulfur dioxide and particulate matter is assumed to be limited by the lesser occurrence of either one or the other pollutant. Consequently, as shown in figure 1, this factor enters the calculation of the city-pollution index (CPI) as the lesser of the value of the impact units per capita for these two pollutants; it is not directly calculated from any ambient air concentration data.

The CPIs are roughly comparable from city to city and provide relative, not absolute, descriptions of urban air quality between cities and over time in any one city. For public policy purposes, the latter time series is very useful not only because it gives a gross picture of air-quality changes, but because it reflects, from its component parts, the possible impacts of air pollution on the population; clearly, such information will suggest control priorities that might provide substantial benefits

Table 3.—Relative severity factors

Pollutant	Units	Ontario 24-hour criteria	Relative-severity factor
Carbon monoxide	ppm	8.00	1
Nitrogen oxides	ppm	.10	80
Oxidants	ppm	.03	267
Sulfur dioxide	ppm	.10	80
Particulates	coefficient of haze per 1,000 ft. of air	1.00	8

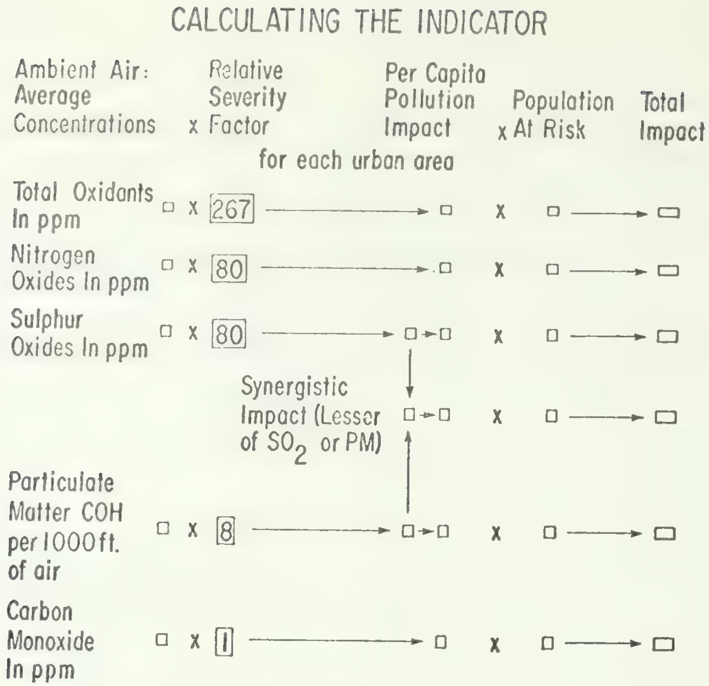

Figure 1.—Calculating the indicator.

—not merely a nebulous statement about the weight or volume of different pollutants in ambient air.

The impact units per capita for each pollutant and synergism are multiplied by the population potentially at risk to yield what we call "impact units." These products are added, by pollutant, for all cities in the sample to yield an "urban pollutant sub-indicator" which provides a comparison, over all cities combined, of the *relative* importance of each pollutant, in any one year, and, when measured over several years, of the emerging or diminishing importance of each pollutant group in respect of all citizens living in all urban areas considered in the compilation of the indicator.

The sum of the urban pollutant Sub-indicators, including synergism, is defined as the "urban air-quality indicator."

The first - approximation - air - quality indicators are, in fact, *social* indicators in that, if all the pollutants had the same annual average concentration in 1975 as in 1974 (and given the constant relative severity factors) and at the same time the population of the cities increased, all urban pollutant subindicators would increase in 1975, implying a fall in the quality of life, in respect to the air environment. In other words, the quality of life (at least in respect to this one aspect of reality) is improved if individuals move from areas of high air pollution to areas of relatively low air pollution, and the converse would also hold; not an unreasonable assumption in our estimation.

Of course, the purpose of improving the quality of life could be more effectively, and probably more economically, achieved by reducing the emissions and thereby the concentration of airborne pollutants. One might note also that dispersion of emissions (by high stack and/or escape-velocity management) could also lower the pollutant subindicators, provided that the pollutants do not merely fall out on some other urban area included in the indicator. This, at one time, implies that dispersion can provide a means to improve urban living standards and yet, that it can only be seen as a partial solution; ideally the compilation of the indicator will be extended to all urban areas (and to rural population where the risk is high). Likewise, as the implications of the impact of air pollution on the nonhuman elements of the environment are incorporated into the relative-severity factors, the inclusion of air-pollution data from rural areas may render the strategy of dispersal less effective in lowering the value of the pollutant subindicators.

Imposing urban-generated costs on the rural portion of the same or other ecosystems of which the city is merely a part, can, and eventually must, reduce the benefits the city and its population must obtain from the countryside.

Finally, like the gross indicators of economic activity (gross national product, price indices, unemployment rates, etc.), the generality of the urban-air-quality indicator provides little more than a glimpse of reality; like its counterparts, however, it can provide comparisons with previous time periods and therefore can generate public and political interest in delving deeper into its component parts and distributional aspects.

SOME RESULTS

The urban-air-quality indicator has been calculated for the years 1971-74 and is plotted on the upper portion of

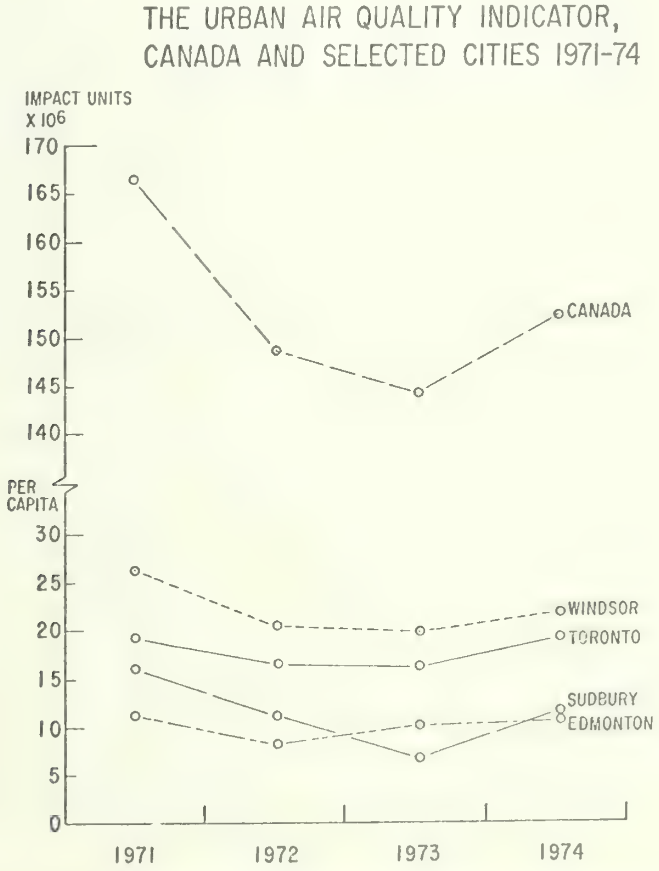

Figure 2.—The urban air-quality indicator, Canada and selected cities, 1971-74.

figure 2. As the graph shows, the indicator fell substantially between 1971 and 1973, reflecting improved air quality. In 1974, however, the indicator rose again, but remained below the 1971 level. In the absence of large population movements over this period, these trends can be attributed directly to changes in ambient concentrations of the pollutants measured.

City pollution indices for four representative urban areas are plotted on the lower portion of figure 2 (the indicator includes data from 11 Canadian cities). With the exception of Edmonton, these cities reflect the national trend of improved air quality through 1973, worsening by various degrees in 1974, the most dramatic reversal taking place in Sudbury.

Further disaggregation, by pollutant, reveals the nature of the decline in air quality in 1974. Figure 3 compares the 1971 and 1974 levels of the pollutant sub-indicators, totalled across the 11 cities. Reflecting traditional concern for air quality in terms of the popular pollutants, and the resulting decline in ambient levels by abatement and dispersion, the indicators for carbon monoxide, sulfur dioxide, and particulate matter have all declined substantially over the 4-year period. The new pollutants, oxidants and oxides of nitrogen, on the other hand, have increased considerably. Since oxidants are formed by photochemical reactions in the atmosphere, for which nitrogen oxides are a necessary input, the increase in ambient concentrations of these two pollutants can probably be explained in terms of emissions of the latter alone.

Nitrogen oxides are one of the products of fuel combustion: if the flame temperature is high enough, atmospheric nitrogen is oxidized. A nationwide inventory of pollutant emissions compiled by the Federal Department of the Environment for 1970 reveals that motor vehicles accounted for some 58 percent of total NO_x emissions, and that stationary combustion such as power generation and incineration accounted for most of the remainder (34 percent of the total).

One can speculate, therefore, that the increase in the subindicators for oxidants and nitrogen oxides reflect the

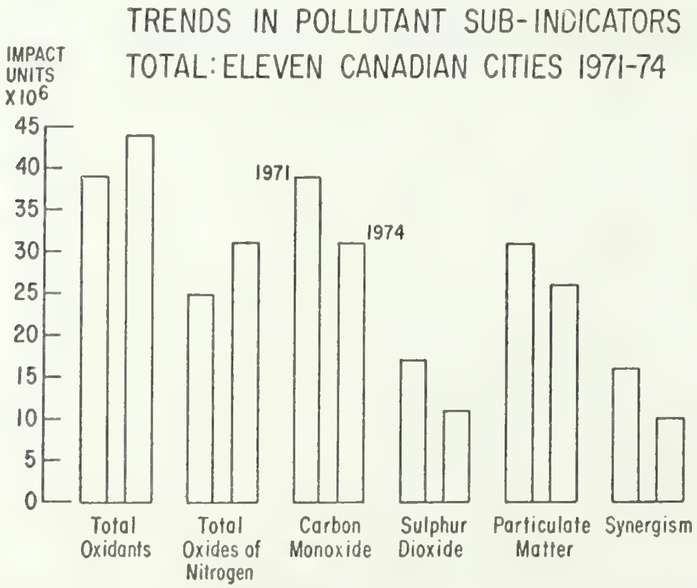

Figure 3.—Trends in pollutant subindicators, eleven Canadian cities 1971-74.

increase in the urban automobile population and the relative lack of control of NO_x by new-car emission standards, at least prior to 1973. The effect of exhaust gas recirculation, first used on some 1973 models, will not significantly reduce NO_x concentrations until these cars make up a significant portion of the automobile age structure.

As a final note on the analytical utility of the indicator, we should point out its "first-approximation" nature. The indicator will be subject to continual modification and improvement as more and better data become available. Specifically, for 1975 and beyond, the indicator will be reformulated, if possible, to consider ozone (as opposed to total oxidants), nitrogen dioxide (versus total oxides of nitrogen), and specific size and chemical descriptions of particulate matter (replacing the coefficient of haze measurements). Finally, the more accurate chemiluminescence technique is coming into wider use for measuring ozone and nitrogen oxide, imparting greater precision to the indicator.

OBJECTIVE OF SOCIAL AND ENVIRONMENTAL INDICATORS

Why have an indicator of air quality in urban centres at all? To repeat some points raised earlier:

- The urban confrontation with the natural environment tends to be abrupt to the point that the air environment is something different from the natural environment in which mankind developed over thousands of years;
- This different environment may have adverse effects on the population that resides in the urban bubbles, and this population represents the bulk of the total population;
- And therefore, if our interest is the maintenance or improvement of the quality of human life, we should have some general information on how this one aspect of the total reality is changing, information that is easily understood by the society and its political leaders.

If the indicator is changing, we (individuals, society, and the decision-makers) will want to know what *controllable* factors are influencing the change and what the distributional aspects of these changes are. This the indicator and its sub-indicators can do. The simplicity of the indicator is "on purpose;" its lack of precision and sophistication makes it meaningful to the *public*, and yet it does not preclude more detailed analysis — it may even encourage it. Finally, one may be critical of the fact that it is a relative measure of air quality rather than a statement of absolute quality — that is, it does not say that at a value of, say, "X" things are "bad," that at "X-Y" things are "good," and that at "X+Y" things are "terrible." Why do we not venture into the debate of absolute air quality? Precisely because air quality is but one part of environmental quality as a whole, and environmental quality is but one aspect of the quality of life as a whole.

Let us emphasize one point. Since the materials that enter production and consumption must equal, in terms of mass, the material content of the products we manufacture and the residuals we generate (less that portion that is recycled), we should be aware that the residuals that are removed from waste gases may simply be reflected in an increase in residuals that we release into the water and land resources of the planet. Quite obviously the net environmental impact of such a transformation may be greater than, equal to, or less than that associated with the equivalent mass of air pollution. Let us ask then, "Which of us can say, *a priori*, that a reduction in air pollutant exposure is automatically a good thing in the wider context of environmental quality and the quality of human life?"

An urban air-quality indicator describes one aspect of the fragile bubble world of the urban scene, but it should be sufficient evidence that man creates unnatural microenvironments. We must all be prepared to examine the viability of this human milieu lest the bubble burst.

Use of a Land-use-based Emissions Inventory in Delineating Clean-air Zones

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ABSTRACT.—Use of a land-use-based emissions inventory from which air-pollution estimates can be projected was studied. First the methodology used to establish a land-use-based emission inventory is described. Then this inventory is used as input in a simple model that delineates clean air and buffer zones. The model is applied to the town of Burlington, Massachusetts. Conclusions and recommendations are offered for the model's use and for interpretation of its results.

THE PURPOSE OF THIS paper is to explore the possibility of using a land-use-based emissions inventory for delineating clean (and polluted) air zones. In this inventory the emission data were averaged and not derived from on-site measurement.

The compiling of this inventory is a two-step process. First a local emissions inventory must be obtained, usually through the federal or state air pollution office. These data will be in the form of amount per time (tons/year) for specific pollution sources. The next step will be to correlate the emissions inventory with a land-use-classification system (MacConnell's land - use - classification system for Massachusetts, 1973). The output of this combination will yield data in the form of amount per area per unit time (tons/acre/year) for each land-use class.

What we are proposing, then, is a land-use-based emissions inventory from which concentration calculations can be made and buffer zones established by using an appropriate dispersion model.

Our particular research project was part of a larger effort devoted to developing the Metropolitan Landscape Planning Model—METLAND *(Fabos 1973)* at the University of Massachusetts. This model inventories and quantitatively assesses a study area in terms of development suitability, resources of special value, and potential for hazards (including air pollution).

The METLAND Model required the assessment of air quality on several scales: regional, town, and site. This was accomplished by using data from the land-use-based emissions inventory as input to three adopted models: Miller and Holzworth *(1967; also Holzworth 1972)*, Hanna *(1971)*, and Turner *(1970)*. For brevity, only the methodology based on Turner will be described here.

OBJECTIVES

The specific study objectives were to: (1) compile a land-use-based emissions inventory as a data base for concentration calculations and (2) adopt a model or technique to convert emissions into concentrations. The procedure was then applied to the METLAND study area of Burlington, Wilmington, and Tewksbury, Massachusetts, three towns in the metropolitan Boston area.

PROCEDURE

Land-Use-Based Emissions Inventory

The procedure for establishing a land-use-based emissions inventory is shown (fig. 1) and the steps explained in the following sections. In the original study, the entire Commonwealth of Massachusetts was inventoried; however, only the Metropolitan Boston Air Pollution Control District (APCD) is referred to here.

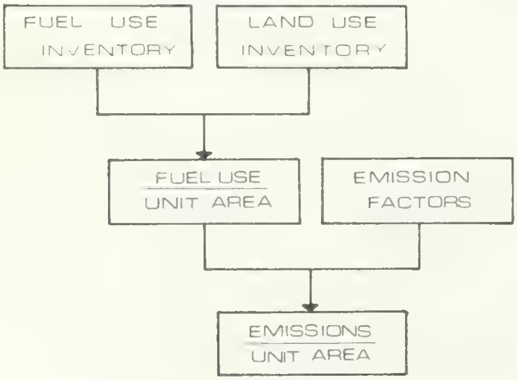
After a land-use-based emissions inventory was established, a model was developed to use that data for delineating clear air (buffer) zones around area sources.

Fuel-Use Inventory

As in 1970, Walden Research Corp. was contracted by the Massachusetts Bureau of Air Quality Control to conduct an emissions inventory for the entire Commonwealth for base year 1972. As before, each APCD was to be inventoried and the totals added to produce an emissions inventory for the entire state. However, at the time (January 1975), only the fuel-use inventory and allocation procedure were completed.

This information was available in a preliminary draft *(Walden, n.d.)*, and the fuel-use inventory (including nonfuel emission data) for area sources was available on computer printouts, both supplied by the Bureau of Air Quality Control. Therefore, we applied the emission factors.

Figure 1.—Procedure for establishing a land-use-based emissions inventory.



It should be noted that for two important sources of pollution, data were unobtainable: electric generating plants and industrial process emissions. Accordingly, they were not represented in the final emissions inventory. Allowances for these omissions will be explained later. Also of note, the 1972 data were applied to METLAND base year 1971, the year of the last land-use inventory by MacConnell.

Land-Use Inventory

William MacConnell *(1973)* inventoried the land use for the Commonwealth of Massachuetts in both 1952 and 1971. This involved aerial photography of the State and interpreting those photographs via a land-use classification system. Then land-use maps were made from the results, and the total number of acres of each land-use class were tabulated for each town and county. This was the land-use system already incorporated into the METLAND model.

Not all the individual land-use classes were needed for the Air Quality Submodel, so these were aggregated according to the Walden draft (table 1). Next, the total number of acres of each aggregate land-use type was tabulated for the Metropolitan Boston APCD for 1971.

Fuel Use/Unit Area

A matrix of aggregated land-use class versus itemized fuel use was constructed for the Metropolitan Boston APCD. The units of this matrix were derived by dividing the amount of a given fuel consumed for a given land use by the number of acres of that land use. Other emission parameters were also treated, such as the number of forest fires/acre of "other" land and the number of landing-takeoff cycles/acre of "airport" land.

The allocation of fuel use and other emission parameters to the land-use

Table 1.—Aggregation of MacConnell's Land-Use Classes

Description* (number of individual land-use types)	Aggregated land-use class code
Low-density residential (6)	URL
High-density residential (3)	URD
Commercial (3)	UC
Industrial (3)	UI
Divided highway (1)	HW
Airports (1)	UTA
Railyards (1)	UTR
Freight and bus terminals (1)	UTT
Docks and waterfront warehouses (1)	UTW
Urban open land (3)	RO
Outdoor recreational facilities (15)	
Mining or waste-disposal areas (5)	
Agricultural and open lands (11)	Other
Forest lands (40)	
Wetlands—except open fresh water (10)	
Open fresh water (1)	W

*For complete descriptions, see MacConnell *(1973)*.

Table 2.—1971 Annual Emission Rates/Acre: Metropolitan Boston APCD

[In lb/yr-acre]

Land use	Pollutant				
	TSP	SO_2	NO_x	CO	HC
URL	10.2	16.8	73.3	525	98.7
URD	281	460	1,950	14,900	2,790
UC Area	1,120	5,080	5,590	15,100	5,490
UC Area + Point	1,210	5,690	5,920	15,100	5,510
UI Area	1,560	3,530	4,560	15,700	9,610
UI Area + Point	2,030	5,300	5,550	16,000	9,750
HW	177	57.4	2,380	8,630	1,970
UTA	238	173	2,730	18,300	2,980
UTR	177	58.3	1,800	14,900	2,600
UTT	184	71.6	1,990	15,000	2,620
UTW	486	2,770	3,830	15,500	3,120
RO	.588	.977	7.81	17.6	4.44
Other	1.25	1.41	8.37	14.3	4.86
W	NIL	.267	.276	138	46.0

classes was made according to the Walden draft and the EPA's APTD-1135 *(1973a)*. Two sets of figures were used for industrial and commercial land uses. One for fuel use by area sources only and the other for fuel use by both area and point sources (those emitting 100 tons/year of any pollutant).

Application of Emission Factors

Using AP-42 *(EPA 1973b)*, emission factors were applied to the values in the fuel-use matrixes to determine amount of pollutant/acre from all sources for the five primary pollutants, total suspended particulates (TSP), sulfur dioxide (SO_2), oxides of nitrogen (NO_x), carbon monoxide (CO), and hydrocarbons (HC) for all land-use classes.

Emissions/Unit Area

Emissions/acre of the five primary pollutants for all land-use classes in the Metropolitan Boston APCD were summed and the totals listed (table 2).

As mentioned previously, electric

generating plants were omitted from the inventory. This omission was not accounted for because few towns (incliuing the study area) have these plants, and because adding these emissions into the inventory would skew the emissions/acre of industrial land, especially for SO_2, making the value too high for typical applications.

Industrial-process emissions were also omitted. Upon checking the previous Walden inventory for 1970, we concluded that such emissions were insignificant, being less than 10 percent of the industrial emissions for any one pollutant.

A MODEL FOR THE DELINEATION OF CLEAN AIR ZONES FOR AREA SOURCES

The establishment of a buffer zone around a high polluting area source will insure that the concentrations of all pollutants (from the source) beyond this zone will be within prescribed standards. Although concentrations may exceed standards within the zone, land use there would be limited to little or no human activity. The method assumes that the area source is the only significant source of pollution in the surrounding area (encompassing about a 2-mile radius around the area source); therefore this method is more applicable to proposed high polluting sources such as industrial and commercial areas. Also, this method is more suitable for somewhat square-shaped area sources. Industrial and commercial point sources those emitting 100 tons/year of any pollutant) should be modeled separately.

General Equation

The basic equation used to determine clean air (buffer) zones is described by Turner *(1970)*. It simulates a square-shaped area source as virtual point source. The concentration at ground level along the centerline of the plume for downwind distance x an effective stack height H is given by:

$$C = \frac{Q\,(10^6)}{\pi\, \sigma_y \sigma_z\, u} \exp\left[-\tfrac{1}{2} \left(\frac{H}{\sigma_z} \right)^2 \right] \left(\frac{Tk}{Ts} \right)^{.20} \qquad [1]$$

Where:

C = Concentration ($\mu g/m^3$)
Q = Emission rate (g/sec)
10^6 = ($\mu g/g$), converts grams to micrograms
$\sigma_y \sigma_z$ = Standard deviations of the concentration distributions (m); determined by x for each stability class
u = Wind speed (m/sec)
H = Effective stock height (m)
Tk = Sampling time for which equation is valid (3 min)
Ts = Desired sampling time (min)

The term $\left(\frac{Tk}{Ts} \right)^{.20}$ is a reduction factor for sampling times greater than 10 minutes. This reduction is due primarily to wind meander over longer periods of sampling time.

If equation 1 is transformed by dividing both sides by Q, then C/Q versus downwind distance (x) can be plotted for various acreages of area sources. The variables in the equation are determined by the certain standard being modeled and by the assumed meteorological conditions associated with that standard.

Governing Pollutant Standard

Upon analyzing the emission rates of the pollutants and their related federal standards, we determined that the secondary 24-hour standard of 260 $\mu g/m^3$ for sulfur oxides, SO_x (measured as SO_2), was the most likely to be exceeded. Therefore, if a buffer zone were established based on this standard for SO_2, then the buffer zone should also be adequate protection from all other area source pollutants (except perhaps oxidants).

Governing Dispersion Conditions

When determining the width of a buffer zone it is usually desirable to use "worst-case" conditions to ensure an adequate margin of safety. The following variable values represent worst-case 24-hour conditions with respect to dispersion meteorology and emission rates.

The values of σ_y and σ_z at a given distance depend upon the stability of the atmosphere. The worst case conditions of stability are class D in the day and class F at night *(Turner 1970)*. These classes were approximated by using class E stability for 24 hours.

The lower the wind speed, the higher the resultant concentrations; however, the lowest common windspeed associated with stability classes D, E, and F is 2 m/sec.

The effective stack height, H, is the total height of pollutant release. This being the sum of the physical stock height plus the plume rise due to the vertical velocity and buoyancy of the released pollutant. The value of H was assumed to be 20 meters (m) in all cases.

The sampling time, Ts, is 24 hours, making the reduction factor $\left(\frac{Tk}{Ts}\right)^{.20}$ = 0.37.

The wind was assumed to meander in accordance with the reduction factor. The buffer zone width was to be determined irrespective of wind direction; therefore the buffer zone would encircle the entire area and be of a constant width.

Specific Equation

When the worst-case values are substituted into the transformed general equation it becomes:

$$/ = \frac{(10)^6}{(3.14)\ \sigma_y \sigma_z\ (2)} \exp\left[-\tfrac{1}{2}\left(\frac{20}{\sigma_z}\right)^2\right](.37) \qquad [2]$$

Now the only remaining variables are σ_y and σ_z which depend upon downwind distance (x). Values σ_y and σ_z from Turner *(1970)* were used.

Graphical Representation of C/Q

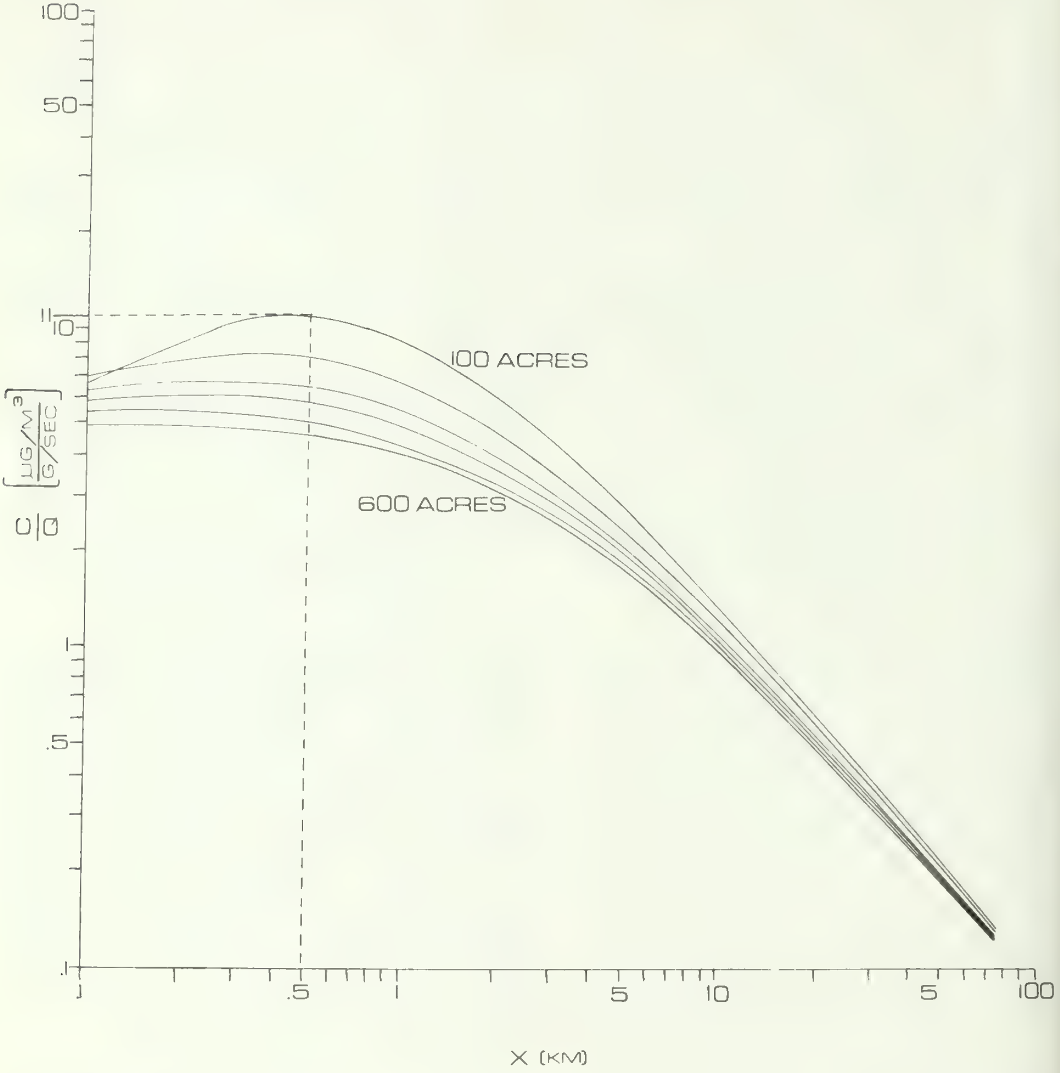
A graph of C/Q versus distance from the edge of the source can be plotted for various acreages. Such graphs (on log-log scales for clarity) were plotted for acreages of 100 to 600 acres (fig. 2).

Determination of Emission Rates

The next step in the procedure was to determine emission rates/acre for SO_2, which when multiplied by the number of acres of the source, and that product multiplied by an appropriate C/Q factor, would yield concentration. The worst emission rates occur on cold days when space heating is at a maximum. For the Metropolitan Boston APCD, the average coldest-day temperature, —10°F (—23°C), occurs in January. However, the chance of the coldest day and worst dispersion conditions coinciding were felt to be rather minimal. A more likely situation would have the worst dispersion conditions occurring on an average cold day of 30°F (—1.1°C). Emission rates were made based upon both temperatures.

To determine 24-hour emission rates/acre for sources having space heating emissions, a method was developed to separate these heating emission from the other daily combustion emissions. By estimating the annual amount of fuel consumed for space heat (the assumption being that this percentage is the same for emissions of space heating) and deducting this from the annual total fuel consumed, the remainder was attributed to fuel consumed for processes. One recent study *(Stanford Research Institute 1972)* gave the following percentages of total energy consumed that was used for on-site space heating in the U.S.:

Figure 2.—C/Q vs. distance from area source.



	Percent	
Residential	79	
Commercial	73	
Industrial	7	(estimated)

To make these figures more representative of the Metropolitan Boston APCD, these percentages were modified with respect to the number of annual degree heating days for the APCD compared with the national average. (Note: The number of degree heating days/day is equal to the number of degrees the average temperature for that day was less than 65°F). The number of annual degree heating days for the Metropolitan Boston area was estimated to be 6300 *(Environmental Science Service 1968)*, and the corresponding figures for the U.S. is 4600 *(Landsberg et al. 1963)*. The modification formula became:

$$Pm = \frac{P \text{ x } \left(\frac{6300}{4600}\right)}{P \text{ x } \left(\frac{6300}{4600}\right) + (100\text{-}P)} \qquad [3]$$

where:

Pm = modified percentage of space heat emissions

P = unmodified U.S. average (both terms expressed as percent)

The modified percentage space heat emissions are:

	Percent
Residential	84
Commercial	79
Industrial	9

Annual space-heating emissions could be determined for a land-use class by first multiplying the total fuel combustion/acre (from the emissions inventory) by the appropriate space-heat percentage. Annual process emissions/acre include the remaining fuel combustion emissions plus annual process losses (estimated from *Morgenstern 1972a, 1972b)*, incineration, and mobile source emissions (table 3).

To obtain a daily emissions rate/acre, first the annual space heating figure (if one existed) was multiplied by the ratio of the number of degree days for that day over the annual total number of degree days. Then the process annual figures was divided by the number of operating days/year. The number of operating days/year were based on the following estimates:

Industry	288 days/year
Commercial	288 days/year
Residential	366 days/year
(inventory was taken on a leap year)	
All other land-use classes	366 days/year

Finally the space heat and process figures for each land use were summed and converted to the metrics of the model, g/sec-acre (table 4).

Table 4.—Emission rates/acre at —10°F and 30°F

[In g/sec-acre]

Land use	Temperature	
	—10°F	30°F
URL	0.000920	0.000450
URD	.0252	.0124
UC Area	.267	.135
UC Area + Point	.300	.152
UI Area	.0775	.0675
UI Area + Point	.116	.102
HW	.000823	.000823
UTA*	.000843	.000843
UTR	.000836	.000836
UTT	.00103	.00103
UTW	.0397	.0397
RO	.0000140	.0000140
Other	.0000768	.0000377
W	.00000383	.00000383

*Uses Berkshire APCD data so as not be skewed by Logan International Airport in Boston.

Table 3.—Annual space heat and process emissions

[In lb/yr-acre]

Land use	Total process					
	Combustion		Process losses	Incineration	Mobile sources	Total
	Space heat	Process				
URL	11.8	2.2	—	—	2.8	16.8
URD	386	17	—	—	57	460
UC Area	3,960	1,050	—	10	60	5,080
UC Area + Point	4,440	1,180	—	10	60	5,690
UI Area	300	3,030	—	140	60	3,530
UI Area + Point	440	4,480	100	220	60	5,300
Other	1.18	.23	—	—	—	1.41

For some industries, especially those involved primarily in research and development, a 9-percent allotment for space heating emissions may be too low. These industries might be better modeled by considering them as commercial sources.

Use of the Model to Determine Buffer-Zone Width

The procedure for determining buffer-zone width is quite simple. The values needed to find the width (x) are the concentration (C), emission rate/acre, and number of acres of the source. Then the C/Q ratio can be determined and the value of x obtained from the previously plotted graph (fig. 2).

The value of the concentration cannot be input as 260 $\mu g/m^3$, the secondary 24-hour standard for SO_2 but must be modified because the ambient temperature is not at standard conditions (25°C = 298°K). To obtain standard temperature correction, a sampled concentration is multiplied by the ratio of ambient temperature (°K) to standard temperature (298°K). Therefore, to find the concentration at −10°F (−23°C, 250°K) that would be equal to a concentration of 260 $\mu g/m^3$ at 25°C, 260 $\mu g/m^3$ must be multiplied by $\frac{298°K}{250°K}$. The modified standard concentration becomes 310 $\mu g/m^3$. The same modification can be made for a temperature of 30°F (−1.1°C, 272°K), yielding a concentration of 285 $\mu g/m^3$.

The same case for modifying temperature can be made concerning pressure; however, normal changes in pressure do not produce significant changes in concentration.

To determine Q, the size of the study area in acres is multiplied by the appropriate emission rate/acre for either −10°F or 30°F.

By dividing 310 $\mu g/m^3$ by Q at −10°F, the buffer-zone width can be determined by using the graph and interpolating, if necessary, between acreage lines. If the C/Q value is greater than any C/Q value on the graph for that acreage, then no buffer zone is required. If a buffer-zone width is obtained from the graph, it can be mapped as a continuous swath around the entire area source. This process can be repeated, using 285 $\mu g/m^3$ and Q at 30°F. Since this emission rate/acre is less than that at −10°F, this buffer-zone width (if one exists) will be smaller.

The outer edge of the −10°F buffer zone represents the zone of no potential hazard from air pollution (except possibly from oxidants and significant line sources.) From the outer edge of the −10°F buffer zone to the outer edge of the 30°F buffer zone represents an area of slight potential hazard. All land within the 30°F buffer zone plus the area source represents a major potential air-pollution-hazard zone.

These zones represent *potential* hazard areas, since emissions were based on average data for the entire APCD. Such zones may be used to site sampling stations for obtaining actual concentrations.

Critical Sources and Acreages

Within the range of acreages considered (100 to 600 acres) only industrial and commercial classes produced enough emissions to exceed the equivalent secondary 24-hour standards. Through an iterative process, the minimum acreages that produce concentrations that exceed the standards were determined (table 5).

The use of this model is illustrated by an application to an area source in the METLAND study area.

APPLICATION

A commercial area source of 105 acres in Burlington was used as an example.

At −10°F, the value of Q became:

$$Q = .267 \text{ g/sec-acre X } 105 \text{ acres} = 28.0 \text{ g/sec} \qquad [4]$$

making the value of C/Q:

Table 5.—Critical area sources

Land use	Temperature (°F)	Critical acreage	Buffer-zone width (km) for the following acreages:					
			100	200	300	400	500	600
UC Area	—10	100	0	1.4	2.1	2.9	3.8	4.7
	30	300	0	0	0	.70	1.1	1.4
UC Area + Point	—10	50*	.70	1.6	2.5	3.5	4.5	5.5
	30	250	0	0	.65	1.1	1.6	1.9
UI Area	—10	800*	0	0	0	0	0	0
	30	>1,000*	0	0	0	0	0	0
UI Area + Point	—10	450	0	0	0	0	.32	.65
	30	500	0	0	0	0	0	.48

*Values were obtained by extrapolation.

$$C/Q = \frac{285\ \mu g/m^3}{14.2\ g/sec} = 20.1 \frac{ug/m^3}{g/sec} \qquad [5]$$

From the graph for 100 acres (fig. 2, dashed lines), if $C/Q = 11 \frac{\mu g/m^3}{g/sec}$, then x = .5 kilometers from the source, meaning a .5 kilometer buffer zone (fig. 3).

At 30°F, the value of Q became:

$$Q = .135\ g/sec \times 105\ acres = 14.2\ g/sec \qquad [6]$$

$$C/Q = \frac{285\ ug/m^3}{14.2\ g/sec} = 20.1 \frac{ug/m^3}{g/sec} \qquad [7]$$

Such a value exceeds those on the graph for 100 acres; therefore no buffer zone is required under these conditions.

CONCLUSIONS AND RECOMMENDATIONS

The threat of a hazard is so slight for the —10° buffer zone that all land uses and activities, except those for critical receptors, can occur there. However, caution should be taken not to group together too many high-polluting land uses of critical or near-critical acreage. Land within the 30°F buffer zone should be of strictly limited land use, with no additional activity planned within the actual buffer zone. The buffer zone should consist of pollutant-resistant vegetation. The possibility of direct source controls within the area source should be investigated.

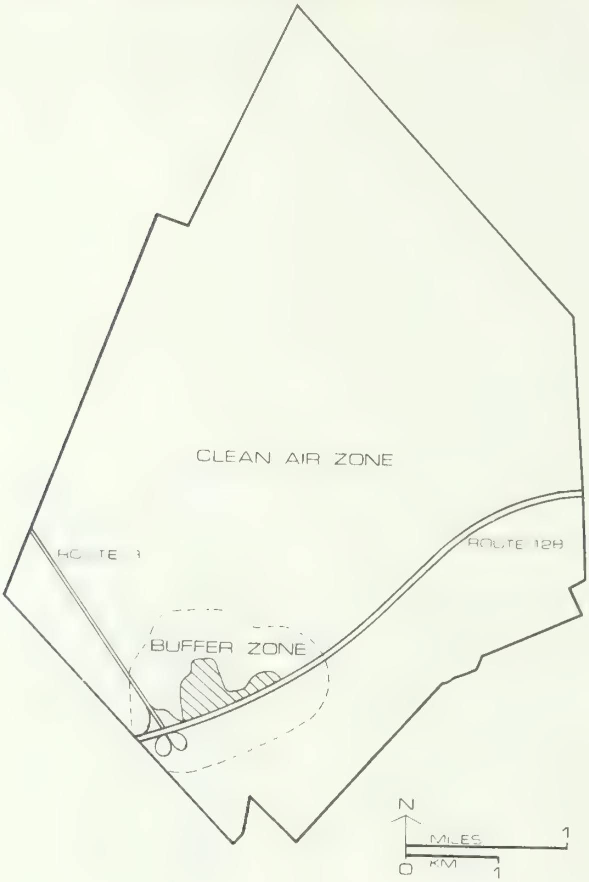
All of the above recommendations are made in the absence of actual air-sampling data. Planning decision may be changed should sampled concentration data become available.

This model and the data generated for its use are better suited for future planning of developable land; however, it can still be applied to existing area sources. Point sources emitting over 100 tons/year should be evaluated separately. If a potential hazard zone should be found, the next step should be the acquisition of specific emission data for recalculation of the model and/or onsite monitoring of air quality. Then, if warranted, a control strategy can be decided.

Of great use to this model would be a correlation of stability, wind speed, wind direction, and temperature with daily concentrations. This could be used to validate the governing conditions assumed in the models. There was not enough time to undertake that task, but such correlation data would be invaluable to these models, and to other models based on 24-hour (or other short-term) standards.

Finally, the process of using empirical data and a simple model offers the planner a relatively fast and noncomplex method of generating air quality information. This process is especially useful in instances where observed data are not available. However, the planner

Figure 3.—Clean air and buffer zones: Burlington, 1971.



must remember that the results are tentative and should be regarded as such.

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Application of the Urban Mixing-depth Concept to Air-pollution Problems

by PETER W. SUMMERS, *chief, Atmospheric Dispersion Division, Atmospheric Environment Service, Environment Canada, Toronto, Canada.*

ABSTRACT.—A simple urban mixing-depth model is used to develop an indicator of downtown pollution concentrations based on emission strength, rural temperature lapse rate, wind speed, city heat input, and city size. It is shown that the mean annual downtown suspended particulate levels in Canadian cities are proportional to the fifth root of the population. The implications of this and other results of the model are discussed.

A LARGE AND INCREASING proportion of the population of North America lives in large cities. Thus by far the largest time-integrated exposure of people to air pollution occurs in urban areas. In spite of improved pollution-control technology, the continued growth of cities and especially of vehicular traffic suggests that there will be no near-term decrease in this exposure. To make rational choices between various land-use and pollution-control strategies, decision - makers require informaton about how the dstribution of emissions and meteorological factors combine to affect urban air-pollution concentrations.

This information can be generated in many ways and can be provided in a wide array of formats. For example, numerical modelling techniques can simulate the ground-level pollution concentrations over the whole city for any given set of source configurations and several typical sets of meteorological conditions. Whilst such results have many valuable uses, they require very detailed source-emission inventories and meteorological data on space and time scales that are usually not available. On the other hand, a simple approach, which gives the pollution concentration in the centre of a city in terms of the major causative factors, also is valuable for urban planners.

In this paper the simple urban heat-island model developed by Summers *(1965)*, using the mixing-depth concept, will be extended to develop an urban pollution indicator in terms of several easily understood and measurable parameters. Some of the implications of this indicator will be discussed—especially in relation to city size and energy use.

THE HEAT-ISLAND MODEL

The phenomenon of the "urban heat island," where night-time surface temperatures on clear nights with light winds are considerably higher in urban areas than in surrounding countryside, has been observed for over 100 years and has been documented extensively in the last 50 years. The most recent comprehensive review on the subject is by T. R. Oke *(1974)*. However, a physical model that could satisfactorily explain the general features of the heat island was not developed until relatively recently *(Summers 1965)*.

The basic concept of this model is shown schematically in figure 1. On clear nights with light winds (<5 m sec^{-1}), a surface-based temperature inversion usually develops in rural areas (that is, the temperature increases with height above the ground). The difference between this vertical temperature profile and the dry adiabatic lapse rate

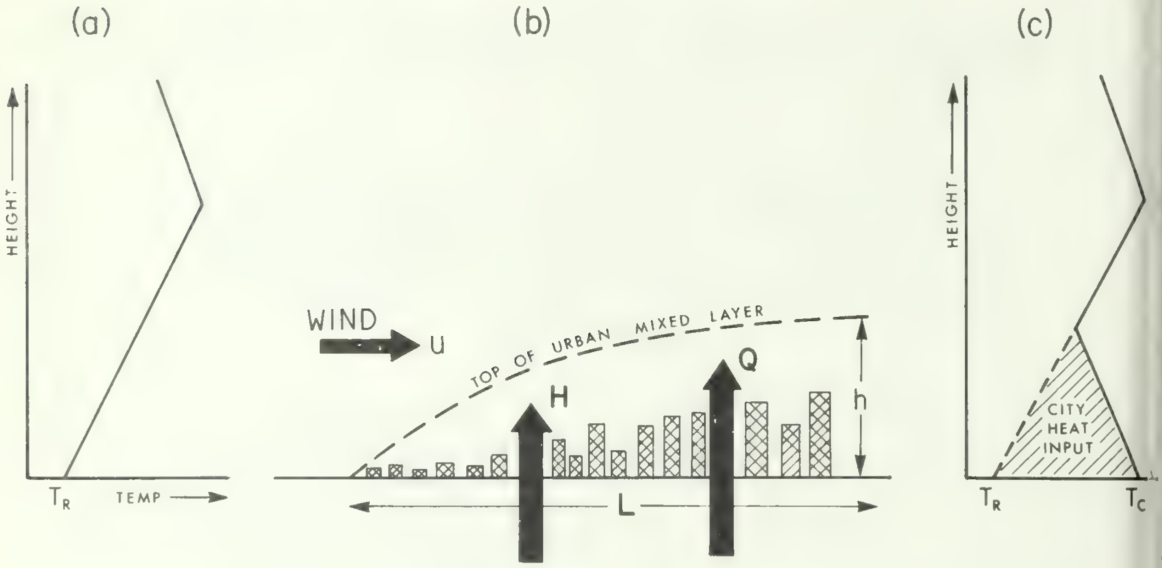


Figure 1.—Schematic representation of the development of the urban mixed layer. (a) The vertical temperature profile upwind of the city with a surface-based inversion. (b) The development of the mixed layer due to urban heat input as air moves from left to right. (c) The vertical temperature profile modified by the city to produce a ground-based unstable layer.

(a temperature decrease of 1°C per 100 m of height, which normally occurs in the lower atmosphere) is defined as a. The stronger the inversion in the rural air, the greater the value of a. As rural air moves in over the city, it is heated from below in two ways.

1. The release of sensible heat stored in the concrete and asphalt fabric of the city from the solar heating of the previous day.
2. The release of waste heat to the atmosphere as a result of the space heating of homes and commercial buildings, industrial activities, and to a lesser extent automobiles.

Source 1 is stronger in the summer, but in the high latitudes of Canada is almost negligible in winter. Source 2 is small in summer, but is the stronger in mid-winter when its strength is proportional to heating degree-days.

Heating of air, combined with increased mechanical turbulence induced by the buildings, produces a layer of well-mixed air over the city, with a temperature lapse rate between the dry adiabatic and isothermal. As the air moves across the city, more and more heat is added, thus causing a steady increase in the height of the mixed layer. As shown by Summers *(1965)* the following relationships can be developed.

$$T_{\mathrm{CITY}} - T_{\mathrm{RURAL}} = \left[\frac{2\,HLa}{\rho C_P u}\right]^{1/2} \qquad [1]$$

$$\text{mixing depth } (h) = \left[\frac{2\,HL}{\rho C_P u_a}\right]^{1/2} \qquad [2]$$

in which:

T_{RURAL} = Temperature in the upwind rural area (°C)

T_{CITY} = Temperature in the downtown core (°C)

L = Distance from the edge of the city to the centre along the wind direction (m)

H = Heat input per unit area (cal m^{-2} sec^{-1})

u = Wind speed (m $\sec^{-1}$)

ρ = Density of air (gm m^{-3})

C_P = Specific heat of air at constant pressure (cal gm^{-1} per °C)

α = Difference between the upwind temperature profile and the lapse rate over the city (°C m^{-1})

THE POLLUTION MODEL

If the urban area acts as a uniform area source of pollutants that are uniformly mixed in the mixing layer, then the concentration of pollution in the city centre is given by

$$\chi_{CITY} = \frac{QL}{uH} = Q \left[\frac{\rho C_P \alpha L}{2uH} \right]^{1/2} \qquad [3]$$

in which:

χ_{CITY} = Pollution concentration in the city (gm m^{-3})

Q = Pollutant input per unit area (gm m^{-2} $\sec^{-1}$)

RELATION BETWEEN POLLUTION AND CITY SIZE

For most urban areas that are nearly circular in shape, the population (P) is given by

$$P = \text{const.} \times L^a$$

If the population density is uniform, $a = 2$. However, in most cities the population density is higher close to the centre due to the high density of older buildings, and especially high-rise apartments. Thus $a \geqslant 2$, hence

$$L = \text{const.}\ P^{1/a} \text{ where } a \geqslant 2$$

Substituting in equation 3

$$\chi_{CITY} = \text{const.} \times Q \times \left[\frac{\rho C_P \alpha}{2uH} \right]^{1/2} \times P^{1/2a} \quad a \geqslant 2 \qquad [4]$$

The mean annual average of a pollutant is heavily influenced by the large values, which in turn occur under those meteorological conditions favouring poor ventilation (simultaneous low values of u and h; or, alternatively, simultaneous low values of u and high values of α). On a cross-Canada basis,

Table 1.—National air-pollution surveillance network: suspended particulates in commercial downtown core areas vs population for 1971

City	Population	Suspended particulates
	Thousands	*μg m⁻³*
Fredericton, N.B.	38	36
St. John, N.B.	107	54
Moncton, N.B.	71	54
Montreal	2,743	132
Ottawa—Hull NCR	602	92
Toronto	2,628	99
Hamilton	499	142
Peterborough	64	61
London	286	125
Sarnia	78	105
Windsor	259	122
Sault Ste Marie	81	55
Thunder Bay	112	69
Winnipeg	540	73
Regina	141	57
Saskatoon	126	72
Edmonton	496	60
Calgary	403	105
Red Deer	28	64
Medicine Hat	29	57
Lethbridge	41	41

Source: Environment Canada (1974).

u is almost constant for Canadian cities, and H tends to be highest where winter inversions are strongest. Thus, $a/_H$ does not vary much from city to city; and hence as a first approximation

$$\chi \quad \begin{pmatrix}\text{annual}\\ \text{mean}\end{pmatrix} = \text{const. x Q x } P^{1/2a} \qquad [5]$$

Apart from a few large industrial sources, particulate emissions in a city are due to a large number of low-level point sources such as home heating units, cars, etc. Assuming that Q is nearly constant from city, then equation 5 reduces to

$$\chi \quad \begin{pmatrix}\text{annual mean}\\ \text{suspended}\\ \text{particulates}\end{pmatrix} = \text{const. } P^{1/2a} \quad a \geqslant 2 \qquad [6]$$

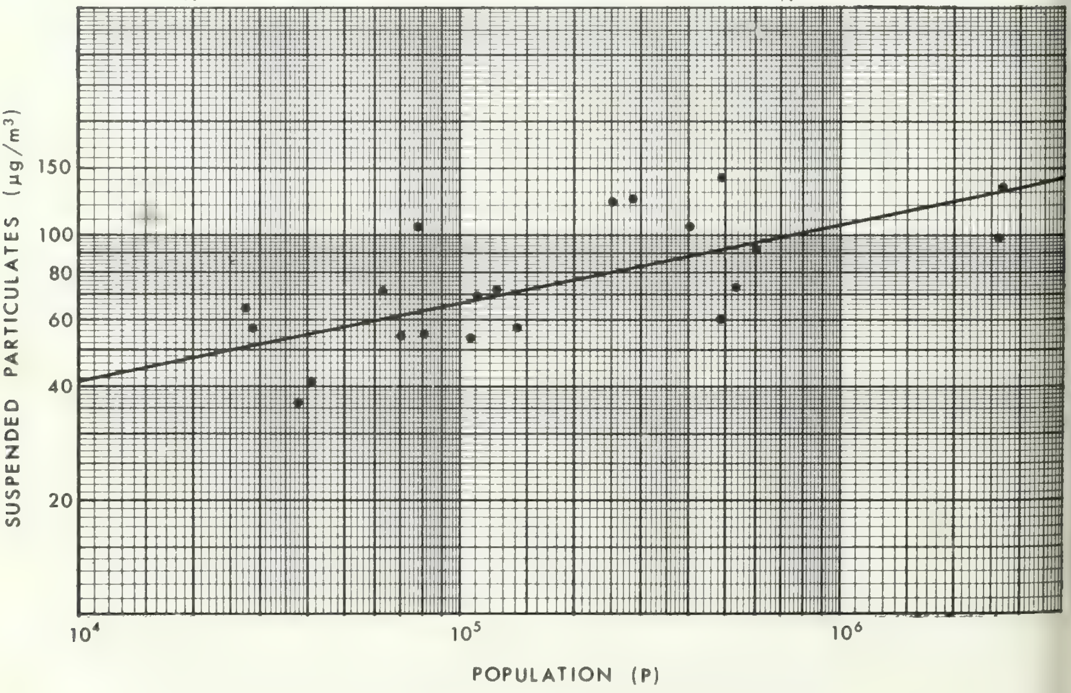
To test equation 6, data from the Canadian Air Pollution Surveillance Network were used (table 1). The population of 21 cities at the time of the last national census in 1971 are listed together with the mean annual suspended particulate levels in the commercial downtown core for the same year *(Environment Canada 1974)*. Note that an effort has been made to locate all these stations in as representative a location as possible away from heavy industry and other large point sources. These data are plotted on log-log paper (fig. 2) and fitted to a power-law curve as shown. The best fit curve is given by

$$\chi = 6.5\ P^{1/5} \qquad [7]$$

with a correlation coefficient between χ and P of 0.69.

Note that the data points above the best-fit line correspond mainly to the heavily industralized cities in southern Ontario. Thus there are probably several lines corresponding to different values of Q (see equation 5), all having a slope of approximately 1/5. It also appears that for Canadian cities a = 2.5.

Figure 2.—Relationship between population of Canadian cities and the mean annual downtown suspended particulate levels in 1971. The best-fit power-law curve is χ=6.5 $P^{1/5}$, with a correlation coefficient between χ and P of 0.69.



SOME IMPLICATIONS OF THE MODEL

$$\chi_{CITY} = \text{const.} \times Q \times \left[\frac{\alpha}{uH}\right]^{1/2} P^{1/5} \qquad [8]$$

This simple indicator shows how various factors combine to produce a measure of the downtown air pollution. Some of these (α and u) are meteorological only. One (P) is dependent on city size only. Others (Q and H) are dependent on both city parameters (mainly population density) and meteorological parameters. For example, one of the components of H, and hence Q, is dependent on heating degree-days.

Several important conclusions can be drawn from this indicator of downtown pollution levels:

1. The main controlling factor is the source strength Q (dependent on population density).
2. Meteorological factors, whilst still important, have less controlling effect due to the square-root relationship.
3. Total population is the least important controlling factor because of the fifth-root relationship.
4. A small town with an average value for Q can have a significant value for χ, but once a city is large (population $>$ 1,000,000), then decreasing the rate of growth will have only a minor impact on χ compared to reducing Q.
5. Increasing the heat input H or decreasing the value of Q, with other factors unchanged, reduces χ. Thus the value of switching to cleaner fuels for home heating: coal → oil → natural gas.
6. Energy conservation could possibly increase χ. If a substantial part of Q were not related to heat production and H were cut back, (due to improved home insulation or other conservation measures) at a greater rate than Q^2, then the value of $Q/H^{1/2}$ could increase, resulting in higher values of χ.

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Air Pollution and Urban Climatology at Norfolk, Virginia

by W. MAURICE PRITCHARD *and* KULDIP P. CHOPRA, *Department of Physics and Geophysical Sciences, Old Dominion University, Norfolk, Va. 23508.*

ABSTRACT.—The atmosphere at Norfolk is usually stable, with no strongly prevailing wind direction. Linear regression analyses of visibility data indicate a generally decreasing visibility trend between 1960 and 1972, with a possible trend reversal in later years. A 44 percent increase in the annual frequency of 0-4-mile visibility occurred in 1960-72. Similar analyses of precipitation data for 1960-74 show a slight increase in the annual number of days with precipitation exceeding 0.01 inch. The correlation coefficient between the annual frequencies of low (0-4-mile) visibility and days with precipitation greater than 0.01 inch was rather small and negative.

NORFOLK IS ONE OF FOUR contiguous cities in the Hampton Roads area in the southeastern corner of Virginia. This area is urban and coastal in character, bordering on the Atlantic Ocean. It has no significant concentrations of heavy industry and is generally well ventilated. However, an analysis of weather data for recent years has shown that local variations in certain meteorological parameters may be associated with the effects of particulate air pollutants.

Air pollution influences urban climatologies in a variety of ways. Among these is a decrease in visibility. A low surface visibility due to air pollutants is now a common occurrence in many urban areas. In other areas where air pollution is not a serious problem, decreasing visibility may serve as an indication of an increasing concentration of air pollutants.

The analysis of visibility data is complicated by the fact that visibility is affected by several meteorological factors as well as by air pollutants. The reduction in visibility due to air pollution is almost always associated with particulate matter in the atmosphere. This reduction is due to scattering and absorption of light by airborne particles. Gaseous pollutants are usually either invisible or present in concentrations too low to affect visibility. However, in sufficiently large concentrations, some gases may produce changes in sky color. A high concentration of NO_2, for example, causes a characteristic brownish discoloration of the sky.

As far as precipitation is concerned, particulate air pollutants may furnish additional condensation nuclei. Significant changes in precipitation patterns have been observed at several cities in studies made as a part of Project METROMEX (Metropolitan Meteorological Experiment).

The influence of a particular type of pollutant depends on the size, concentration, and physical properties of the particles. The particle concentration is related to the air volume occupied. This mixing volume can be estimated by using as a vertical dimension the height of the base of a low-lying temperature inversion. Winds serve to dilute the concentration of atmospheric particulate matter by increasing the mixing volume. Low-level atmospheric turbulence also has a diluting effect.

VISIBILITY

In recent years, declining visibility attributed to air pollution has been reported at or near a number of urban areas. These include: Tucson, Arizona *(Green and Battan 1967)*; Point Mugu, California, near Los Angeles *(Lea 1970)*; Los Angeles, *(Chass and Keith 1971)*; Akron, Ohio, Lexington, Kentucky, and Memphis, Tennessee, *(Miller et al. 1972)*; and Norfolk, Virginia, *(Pritchard and Chopra 1972)*. The periods considered were 1949-65 by Green and Battan, 1949-69 by Lea, 1933-69 by Chass and Keith, 1962-69 by Miller et al., and 1960-70 by Pritchard and Chopra. The most pronounced effect observed by all these investigators was a generally increasing trend in the frequency of low visibility. The earlier visibility study by Pritchard and Chopra *(1972)* has now been extended by 4 years and expanded to include consideration of atmospheric stability, wind conditions, and precipitation.

The visibility data analyzed were recorded at the Norfolk Regional Airport in Norfolk, Va. In particular, visibilities measured at noon EST on weekdays were examined for the 15-year period 1960-74. This choice of data is the same as that made by Chass and Keith *(1971)* for the Los Angeles study.

The mean annual visibilities from 1960 to 1972 (fig. 1) show a slight trend toward reduced visibility. The solid line is the linear regression line given by

$$\bar{V} = 8.20 - 0.0275\,N \qquad [1]$$

where V is the mean annual visibility in miles and N = 1, 2, 3, . . . 13 is the year index beginning with N = 1 for 1960. The regression line indicates a slight decreasing trend over the 13-year period. However, a reversal of this trend may have occurred, possibly beginning in 1972. The mean annual visibilities for 1973 and 1974 were 9.17 and 9.57 miles respectively. These values

Figure 1.—Mean annual visibility, 1960-72.

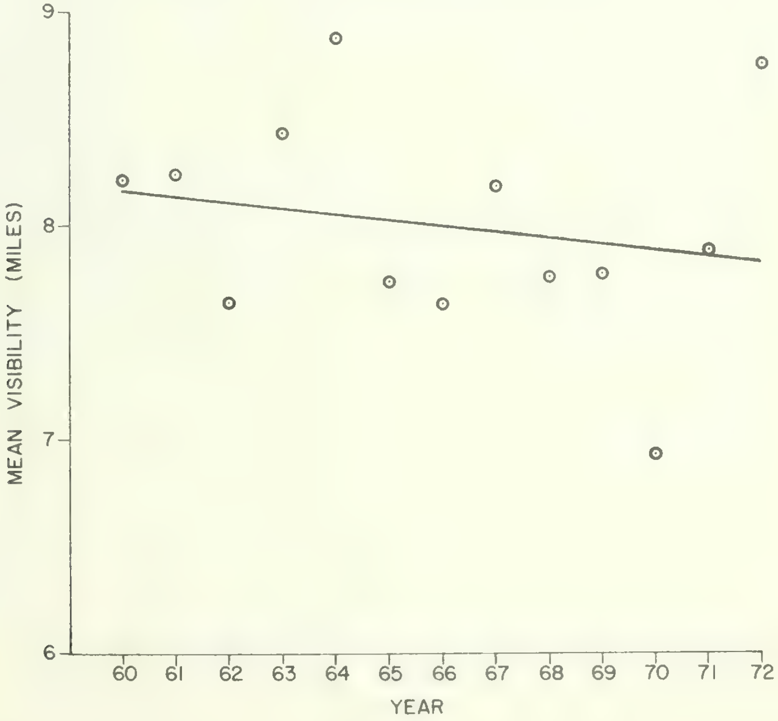


Figure 2.—Annual frequency of 0-4-mile visibility, 1960-72.

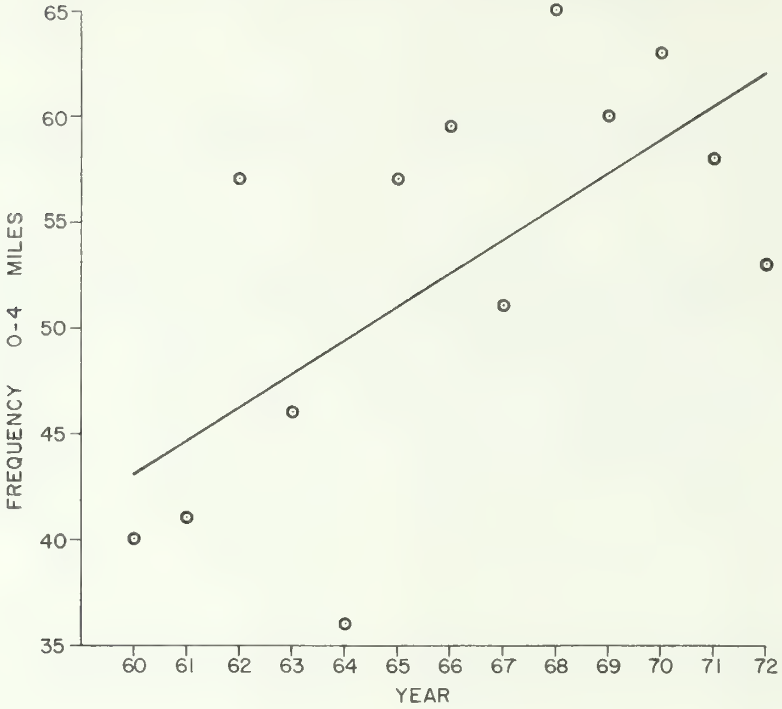
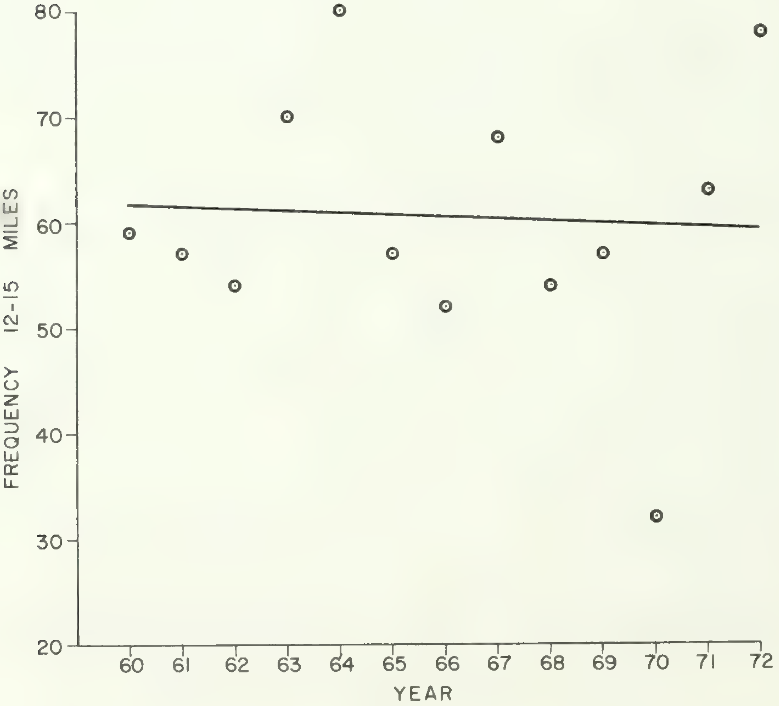


Figure 3.—Annual frequency of 12-15-mile visibility, 1960-72.



are considerably higher than the values given by the regression line.

The annual frequencies of occurrence of visibilities in the 0-4-mile range (fig. 2) for the period 1960-72 fit the regression line

$$F=41.5+1.58\ N \qquad [2]$$

where F is the annual frequency. In this case, a significant increasing trend is observed. The frequence of occurrence of low visibilities, as given by the regression line, increased by 44 percent between 1960 and 1972. A possible trend reversal after 1972 was observed here also. The frequencies of occurrence of visibilities in the 0-4 mile range decreased to 48 in 1973 and to 41 in 1974.

An increase in low visibilities might be expected to indicate a concurrent decrease in high visibilities. The annual frequencies of occurrence of visibilities in the 12-15-mile range (fig. 3) from 1960 to 1972 bear this out. The regression line for these high visibilities is given by

$$F=61.0—0.132\ N \qquad [3]$$

This equation indicates a slight decreasing trend for high visibilities. The data for 1973 and 1974 do not follow this trend. The annual frequencies of occurrence for visibilities in the 12-15-mile range were 102 in 1973 and 205 in 1974. Both of these frequencies are far above the regression line.

PRECIPITATION

The availability of condensation nuclei from anthropogenic sources may lead to increased precipitation patterns in and around urban areas. To investigate this effect, we examined precipitation data from the Norfolk Regional Airport weather station. Data on total annual precipitation, P, (fig. 4) and

Figure 4.—Total annual precipitation, 1960-74.

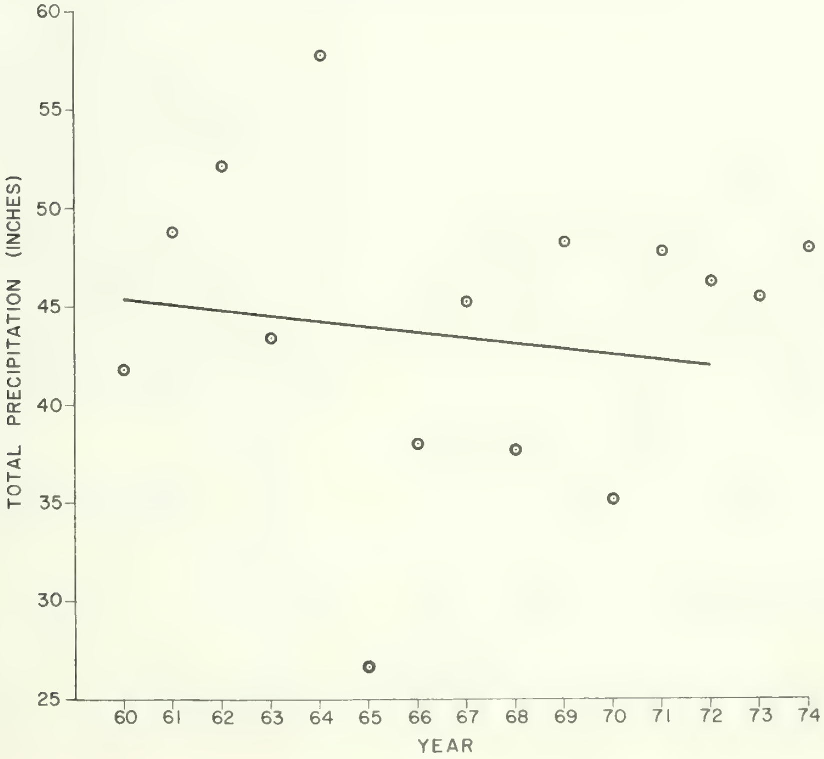
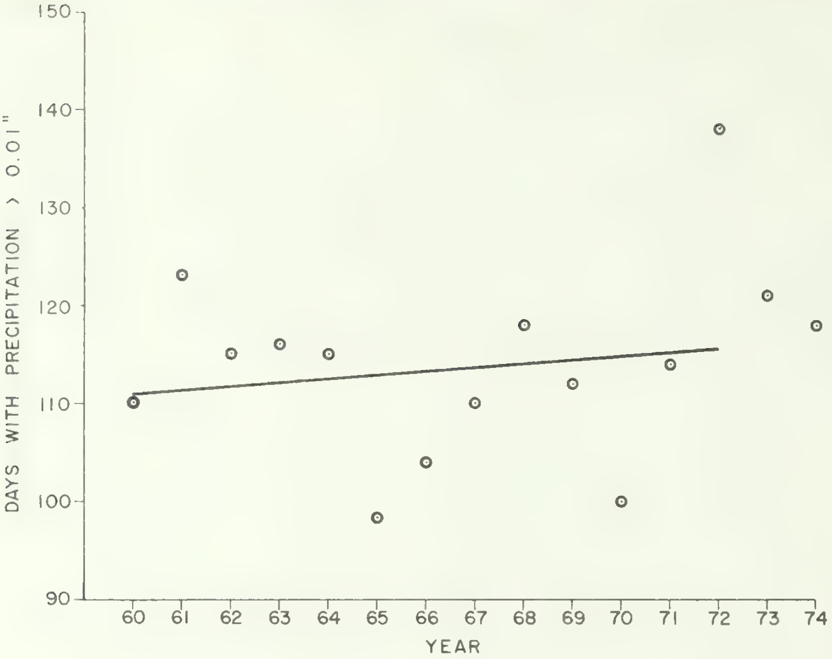


Figure 5.—Annual frequency of days with precipitation greater than 0.01 inch, 1960-74.



annual number of days, F_P, with precipitation greater than 0.01 inch (fig. 5) were considered for the period 1960-74. The regression lines for the data through 1972 are described by

$$P = 45.7 - 0.284\,N \text{ inches} \qquad [4]$$

and

$$F_P = 110.7 + 0.379\,N \text{ days} \qquad [5]$$

A slight decreasing trend in P and a slight increasing trend in F_P is apparent. The value of F_P computed from the regression equation increased by 4 percent between 1960 and 1974. An examination of the precipitation data (figs. 4 and 5) shows that the data points for 1973 and 1974 follow the trends of the regression lines based on data for the period 1960-72.

AIR FLOW CHARACTERISTICS

The atmospheric flow characteristics of a region have an important bearing on the rate of dispersal of pollutants. These characteristics can be classified as wind speeds and directions and atmospheric stability. The extent of vertical air motion is related to the atmospheric lapse rate, which determines whether vertical motion is enhanced or diminished.

The annual distribution of wind directions (table 1) and frequency of Pasquill stability classes (table 2) were

Table 1.—Annual distribution of wind directions

Wind direction	Distribution
	Percent
N	9.1
NNE	7.1
NE	5.6
ENE	6.6
E	7.1
ESE	3.0
SE	3.9
SSE	5.8
S	9.1
SSW	10.5
SW	6.2
WSW	5.7
W	7.5
WNW	4.0
NW	3.7
NNW	5.1

Table 2.—Annual frequency of Pasquill stability classes

Stability class	Frequency
	Percent
A. Extremely unstable	3
B. Unstable	7
C. Slightly unstable	12
D. Neutral	47
E. Stable	32

determined from data recorded at the Norfolk Naval Air Station between December 1966 and November 1971. The data for this weather station are considered representative of the area, and hourly measurements are made. It appears that, on an annual basis, there is no pronounced prevailing wind direction.

The regional atmosphere at Norfolk displays a generally high stability, which is not usual for an urban area. Normally Pasquill stability class C (slightly unstable) would prevail in an urban environment. This is due to the greater surface roughness and higher temperature environment of cities as compared with rural areas. It is significant that, at Norfolk, stability classes D (neutral) and E (stable) account for 79 percent of all occurrences.

The reasons for the high stability in Norfolk are to some extent geographical. The Norfolk metropolitan area is on a peninsula, and the surrounding water, with low surface roughness, increases the stability of the air passing over it and thus reduces the urban effect. In general, high atmospheric stability is not conducive to the dispersion of air pollutants.

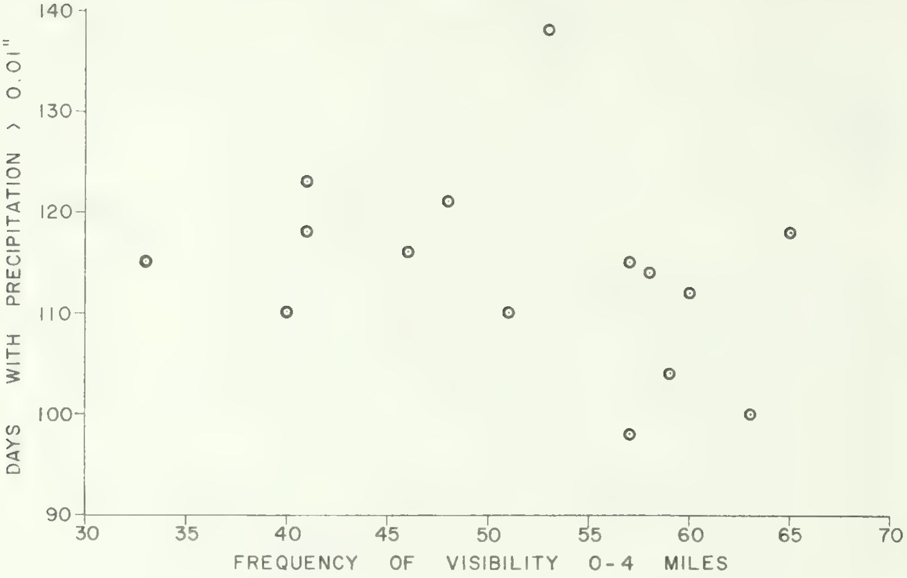
DISCUSSION

A significant decrease in visibility at Norfolk occurred during the 13-year period 1960-72. This decrease may be related to an increasing atmospheric concentration of particulate air pollutants. The most pronounced effect was a substantial increase in the annual frequency of occurrence of low (0-4 mile) visibilities. This result is in agreement with the findings of other investigators for time intervals ending in the late 1960s. For example, Chass and Keith *(1971)* observed that the noon weekday visibility at Los Angeles showed a marked increase in the annual frequency of visibilities in the 3-6-mile range for the 37-year period 1933-69. The declining visibility at Norfolk was associated primarily with sharply lower visibilities during the summer months. This can be attributed to the combined effects of increasing air pollution and a seasonal high in relative humidity. Hygroscopic particles in the atmosphere absorb water and increase in size when the relative humidity is high but the air is unsaturated. Larger particles are more effective in reducing visibility. The same seasonal effect has been observed by Miller et al. *(1972)*.

The extremely high visibilities observed at Norfolk during 1973 and 1974 are somewhat difficult to account for. Some reduction in the generation of particulate air pollutants has occurred. The Virginia Air Pollution Control Board began in 1972 to enforce regulations designed to reduce air pollution from point sources. In the Norfolk Area, the principal point sources of particulate air pollutants were incinerators and businesses engaged in the production of asphalt and fertilizers. Since 1972, particulate emissions from these sources have substantially decreased. However, the extent of the reduction in particulate emissions from heating systems and automobile engines is uncertain.

Precipitation data for the entire 1960-74 period show a slightly increasing trend in the annual frequency of days with precipitation greater than 0.01 inch. This effect may also be due to particulate air pollutants. In addition, some correlation between visibility and precipitation data might be expected. A cross-correlation plot of the annual frequency of days with precipitation ex-

Figure 6.—Correlation between visibility and precipitation, 1960-74.



ceeding 0.01 inch versus the annual frequency of visibility in the 0-4 mile range is shown in figure 6. The correlation coefficient in this case, for the entire 1960-74 period is

$$\rho = \frac{\sum_{i=1}^{15} (F_{vi} - \bar{F}_v)\,(F_{Pi} - \bar{F}_P)}{\left[\sum_{i=1}^{15} (F_{vi} - \bar{F}_v)^2 \sum_{i=1}^{15} (F_{Pi} - \bar{F}_P)^2\right]^{1/2}} = -0.296 \qquad [6]$$

Here F_{vi} and F_{Pi} are the annual frequencies for visibility and precipitation respectively, and $\bar{F}_v$ and $\bar{F}_P$ are the 15-year averages of the F_{vi} and F_{Pi} values. The correlation coefficient, although rather small, is negative and is consistent with the hypothesis that the effect of precipitation is to increase visibility by washing particulate matter out of the atmosphere.

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Development of Alternative Sulfur Dioxide Control Strategies for a Metropolitan Area and its Environs, Utilizing a Modified Climatological Dispersion Model

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ABSTRACT.—Alternative control strategies were developed for achieving compliance with ambient air quality standards in Portland, Maine, and its environs, using a modified climatological dispersion model (CDM) and manipulating the sulfur content of the fuel oil consumed in four concentric zones. Strategies were evaluated for their impact on ambient air quality, economics, and fuel oil resources. Based on these evaluations, a control strategy best suited for meeting the needs of the Portland area could be recommended.

IMPLEMENTATION PLANS for meeting ambient air quality standards were prepared by most states in the early 1970s pursuant to requirements of the Clean Air Act of 1970. These plans mandated various measures for controlling pollutant emissions to ensure compliance with the standards. However, implementation of the control strategies met with varying degrees of success.

Prompted by the failures, reevaluations of control strategies in the past year have highlighted a number of questionable approaches in strategy development. For example, a major shortcoming in the development of many strategies was the assumption that all pollutant sources should be controlled by the same percentage amount to achieve improved air quality. This approach to strategy development was commonly called the "rollback" procedure.

The rollback procedure was the basis for establishing in 1972 the control strategy *(Maine Dep. Environ. Protect. 1972)* for sulfur dioxide emissions in the Metropolitan Portland Air Quality Control Region (AQCR). The Portland AQCR encompasses Cumberland, Sagadahoc, and York Counties and a small portion of Oxford County in southern Maine (fig. 1). A substantial body of air quality data has been collected in the region in the past several years by the State Department of Environmental Protection and industrial concerns. All monitoring data indicate that ambient sulfur dioxide concentrations throughout the AQCR are well below the federal EPA standards except in the downtown area of Portland. There, violations of federal and state 24-hour average and annual average standards have been and continue to be recorded. Measured 24-hour average sulfur dioxide concentrations at one location in the downtown Portland peninsula have exceeded the state standard by 100 percent, and measured annual average levels have exceeded the standard by 50 percent.

Recent examinations of air quality data collected in the Portland AQCR since 1972 indicated that the originally developed rollback strategy would be ineffective in solving regional air quality problems. Realizing that there were several alternatives for solving the re-

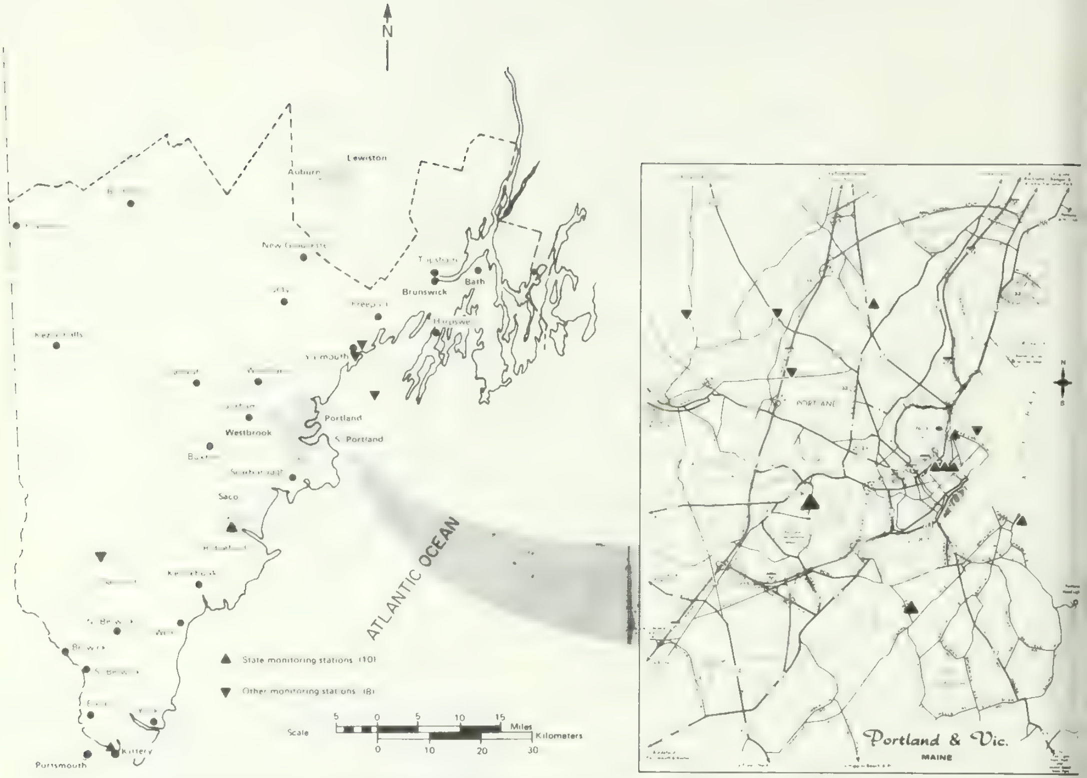


Figure 1.—The Maine Metropolitan Portland Air Quality Control Region.

gional problem, the Maine Board of Environmental Protection heard evidence on alternative control strategies from the Maine Department of Environmental Protection and all other interested individuals. These opinions and suggestions were presented before the Board at a public hearing on 16 April 1975. The thorough reevaluation and development of the Portland sulfur dioxide control strategy, which is described in this paper, was presented at that time.

REGIONAL AIR QUALITY MODEL AND MODEL VALIDATION

The Climatological Dispersion Model (CDM) developed by the federal Environmental Protection Agency *(Calder 1973, Busse and Zimmerman 1973)* was the principal tool used to evaluate both the regional air quality problem and, subsequently, alternative solutions. The CDM is a computer code that uses input data on pollutant concentrations based on generally accepted principles.

CDM's emission inventory input capability was expanded to accommodate different categories of fuel use for both point and area sources and for different geographical areas. The purpose of this modification was to permit testing of the effect on ambient air quality of variation in the sulfur level in fuel oil both as a function of fuel type (No. 6, No. 4, and No. 2) and as a function of geographical area (downtown and suburbs).

To use CDM in the Portland AQCR, the model had to be validated for application to both 24-hour and annual time periods. This important first step was accomplished by assembling an extensive data base comprised of ambient sulfur dioxide concentration measurements, meteorological observations, and a sulfur dioxide emission inventory.

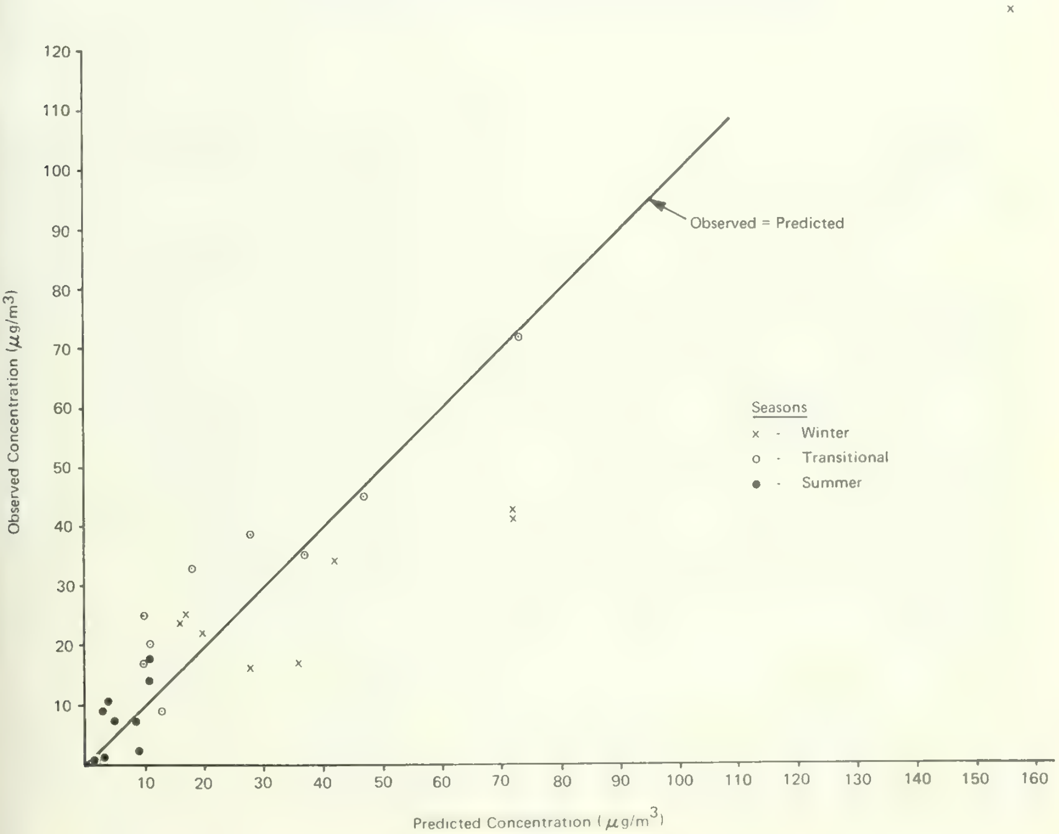
The year October 1973 through September 1974 was selected for validating CDM over an annual period because the most comprehensive set of sulfur dioxide measurements were available for this period. This data set included continuous measurements at two downtown sites and two suburban sites and measurements on an every-sixth-day schedule at seven additional sites in the AQCR. Meteorological data were assembled from the National Weather Service station at the Portland International Jetport.

A total of 8 days in 1973 were selected for validating CDM for application to 24-hour periods. The days selected include 5 on which the sulfur dioxide concentration measured in downtown Portland was the highest recorded at street level in the Portland AQCR.

CDM was successfully validated for both 24-hour and annual periods for the Portland AQCR based on comparisons of calculated and observed concentrations. The correlation coefficient for calculated and observed concentrations at the monitor location of maximum concentration, the Masonic Building in downtown Portland, was 0.78 for 24-hour periods. The correlation for all monitoring locations in the AQCR was 0.67 for 24-hour periods.

The correlation coefficient for all calculated and observed annual average concentrations in the AQCR was 0.96. These annual averages were calculated by taking the mean of three seasonal averages (fig. 2). Seasonal averages were

Figure 2.—Seasonal predicted versus observed sulfur dioxide concentrations in the Portland AQCR, 1973-74.



calculated because of the large variability, typically an order of magnitude, in ambient sulfur dioxide levels from winter to summer. Generally, CDM-predicted concentrations were higher than observed concentrations for both 24-hour and annual periods.

AIR QUALITY PROJECTIONS

Numerous violations of the 24-hour standard and several violations of the annual ambient air quality standard for sulfur dioxide have been recorded in downtown Portland. If no controls are placed on sulfur dioxide emissions, it is reasonable to assume that such violations will recur. These recurrences will probably increase in severity and frequency because of the additional sulfur dioxide emissions that accompany population growth. Hence, any plan designed to resolve the existing problem must also account for worsening of the problem due to such growth. Furthermore, the federal EPA requires that control strategies account for projected growth in an AQCR over the next decade.

Growth is not the only factor that must be considered in designing a control strategy. Meteorological conditions vary from day to day and from year to year. Because the Maine standards allow for no 24-hour average or annual average concentration of sulfur dioxide above the standard, it is only prudent to account for the most adverse meteorological conditions that might be expected over a 24-hour and annual period during the coming decade.

Projections to the data base were made to account for both increased sulfur dioxide emissions due to population growth and the most adverse meteorological conditions. Projected growth in the AQCR was accounted for through 1985 by proportionally increasing the area source emission inventory. Additionally, all emissions were increased to account for increased heating requirements due to very cold weather. Finally, the most adverse meteorological conditions that might be expected over the next 10-year period were projected. The projected emission inventory and meteorological conditions were then combined in CDM to calculate the worst probable air quality levels through the year 1985.

The projected maximum sulfur dioxide concentrations for 24-hour and annual periods consistently fell below the standards except in the downtown Portland peninsula. There, maximum levels projected by CDM exceeded the standards by larger margins than had recorded maximum levels. The projected peak 24-hour average sulfur dioxide concentration is 550 micrograms per cubic meter at the Masonic Building, with projected peak levels above the standard of 230 micrograms per cubic meter over most of the downtown Portland peninsula (fig. 3 and 4). The projected peak annual average is 97 micrograms per cubic meter, again at the Masonic Building, with projected peak levels above the standard of 57 micrograms per cubic meter in the center of the peninsula (table 1).

DEVELOPMENT AND EVALUATION OF ALTERNATIVE CONTROL STRATEGIES

The air quality projections essentially defined the extent and magnitude of the sulfur dioxide air quality problem in the AQCR through 1985. Using CDM as a tool, alternative strategies for solving the problem were developed and evaluated. In addition, an assessment of the impact of these strategies on fuel costs was included in the evaluation.

Following the approach to the problem of the rollback strategy, an average fuel sulfur content limit required throughout the AQCR to meet state standards could be determined using CDM. However, in this study, the approach taken was to examine the problem and develop solutions specifically tailored to the problem.

Violations of the 24-hour and annual

Figure 3.—Predicted peak 24-hour concentrations, northwest wind. (Concentration in $\mu g/m^3$.)

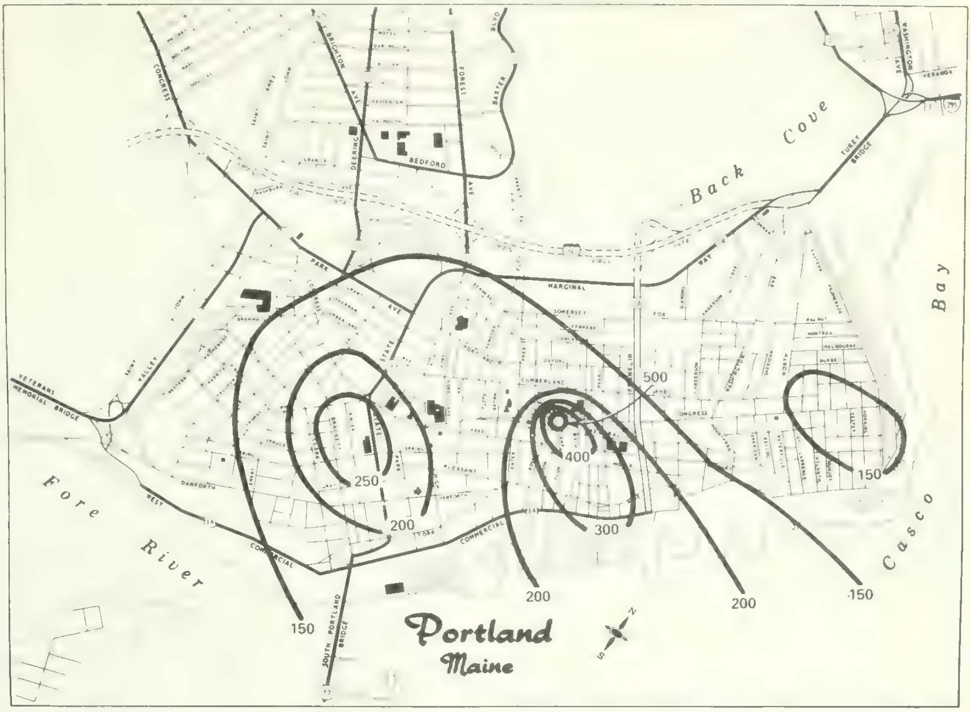


Figure 4.—Predicted peak 24-hour concentrations, southwest wind. (Concentration in $\mu g/m^3$.)

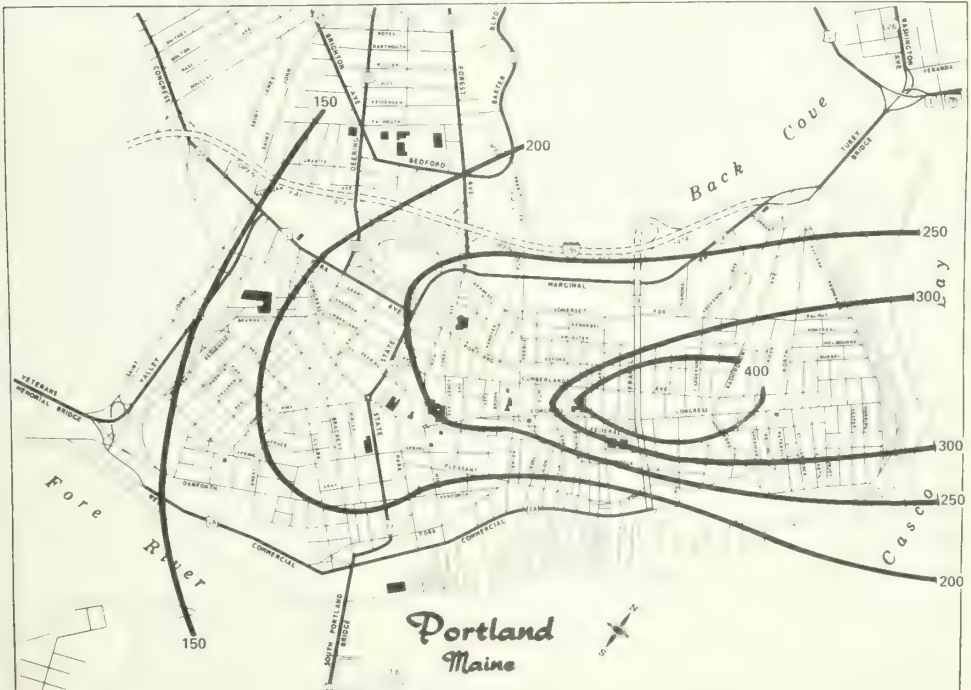


Table 1.—Average fuel sulfur contents required to achieve compliance with state standards for each alternative control strategy

Alternative control strategy	Area of fuel sulfur content control	Average sulfur content No. 6 fuel	No. 4 fuel	No. 2 fuel
		Pct.	*Pct.*	*Pct.*
24-hour compliance:				
A	Downtown Portland Peninsula	0.7	0.7	0.25
B	Portland and South Portland	.8	.8	.25
C	Portland SMSA	.9	.9	.25
D	Entire Portland AQCR	.9	.9	.25
Annual compliance:				
A	Downtown Portland Peninsula	.9	.9	.25
B	Portland and South Portland	1.0	1.0	.25
C	Portland SMSA	1.1	1.1	.25
D	Entire Portland AQCR	1.1	1.1	.25

sulfur dioxide standards were projected in the downtown Portland peninsula only. The highest 24-hour average levels were projected for areas along Congress Street in the center of the downtown peninsula. The major contributors to this problem were identified by the CDM as the users of residual oil in the downtown peninsula. Because the problem was geographically isolated, control strategies for fuel oil sulfur content were developed with a major focus on geography.

Four alternative strategies to bring sulfur dioxide levels in the downtown area into compliance with air quality standards were formulated. These strategies consisted of controlling sulfur dioxide emissions only within specific geographical areas by selectively reducing the average sulfur contents of heavy fuels within these areas alone.

The four alternative strategies differed only in respect to the geographical area within which the controls were exerted. The four geographical areas within which fuel sulfur level controls were exerted are listed below:

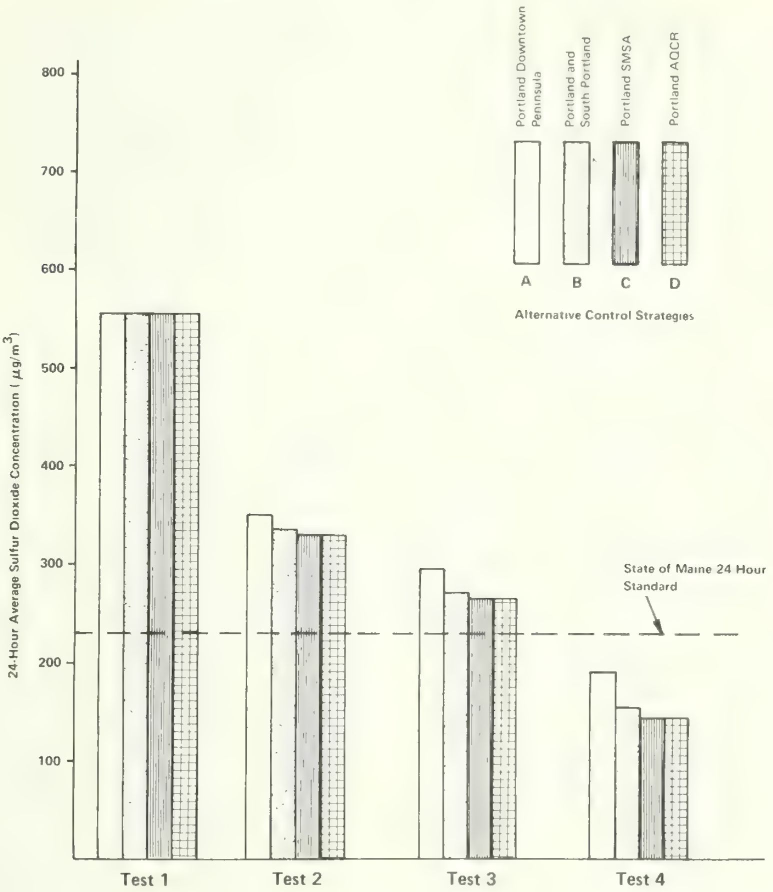
1. Alternative A—Controls on fuel sulfur content within the downtown peninsula only of the city of Portland (the dividing line between the mainland and the peninsula was taken as Interstate 295).
2. Alternative B—Controls on fuel sulfur content within the cities of Portland and South Portland only.
3. Alternative C—Controls on fuel sulfur content within the metropolitan Portland area only (defined as the U. S. Census Bureau's Portland Standard Metropolitan Statistical Area, which includes Portland, South Portland, Cape Elizabeth, Scarborough, Westbrook, Gorham, Cumberland, Falmouth, and Yarmouth).
4. Alternative D—Controls on fuel sulfur content within the entire Portland AQCR.

The CDM predictions showed convincingly that the current average sulfur contents of heavy fuels must be reduced to meet ambient air quality standards. To determine the average sulfur contents of heavy fuels required to meet the standards for each alternative strategy, a series of CDM tests were run. Progressively lower average sulfur contents of No. 6 and 4 fuel were used in each successive test, as defined below, with No. 2 fuel at an average sulfur content of 0.25 percent in all cases.

Test 1—Existing average sulfur contents of heavy fuel oils, with No. 6 at an average of 2.3 percent and No. 4 at an average of 1.27 percent.

Test 2—No. 6 fuel average sulfur content reduced to that of No. 4 fuel, with both No. 6 and No. 4 at an average of 1.27 percent.

Figure 5.—The 24-hour test sequence for the locus of maximum predicted concentration at the Masonic Building monitor.



Test 3—No. 6 and 4 fuel average sulfur content reduced, with both No. 6 and No. 4 at an average of 1.0 percent.

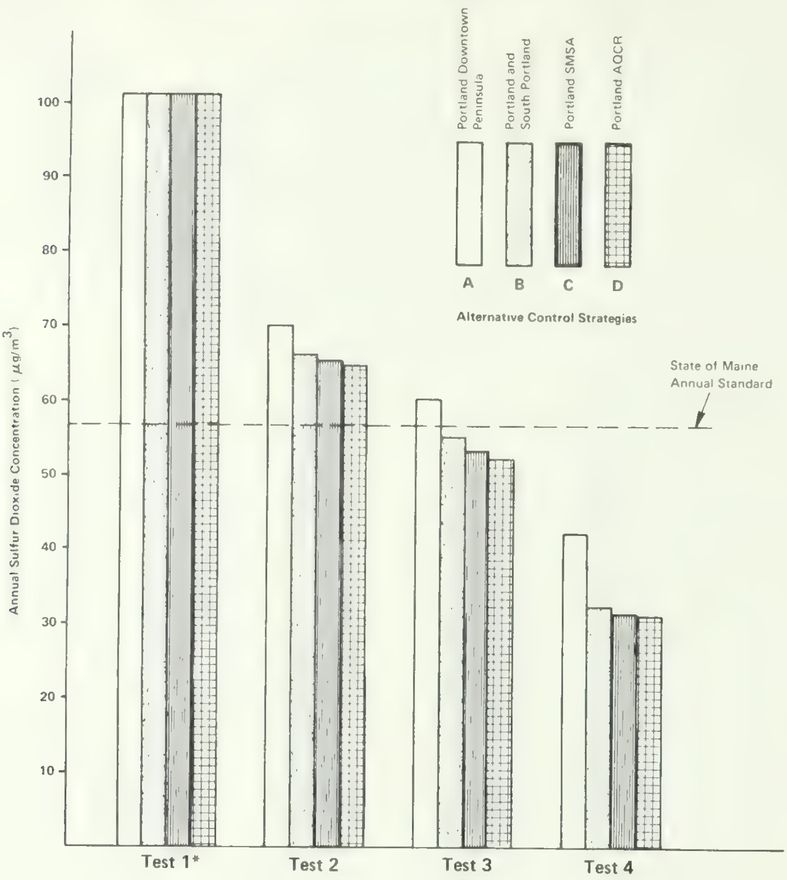
Test 4—No. 6 and 4 fuel average sulfur content further reduced with both No. 6 and No. 4 at an average of 0.5 percent.

Test 1, of course, represents worst-case projections without controls. Projected ground-level concentrations at the location of maximum concentration in the Portland AQCR, which is at the Masonic Building monitor, were shown for the 24-hour period and for the annual period. These concentrations represent the magnitude of peak sulfur dioxide concentrations under projected worst-case meteorological and emission-rate conditions. Both projections show that ambient concentrations would exceed state standards by a considerable margin.

In test 2, the average sulfur content of No. 6 fuel was reduced from 2.3 to 1.27 percent, the same average sulfur content as No. 4 fuel. The predicted ground-level concentrations for test 2 still exceeded state standards for both the 24-hour (fig. 5) and annual (fig. 6) time frames for all alternative strategies.

Predicted concentrations for the 24-hour case of test 3 continue to exceed the state standards for all alternative strategies. However, for the annual case the standard is exceeded only with al-

Figure 6.—Predicted annual sulfur dioxide concentration for alternative control strategies, Masonic Building monitor.



ternative A. The remaining alternative strategies bring levels below the standard and are acceptable strategies for assuring compliance with the state sulfur dioxide annual standards.

As anticipated, achieving compliance with the 24-hour standard requires a more restrictive fuel sulfur content than required to achieve compliance with the annual standard. Although compliance with the annual standard may be possible at the test 3 sulfur content level with alternative A, the same sulfur combination in fuel oils will not meet the 24-hour state standard (see comparisons, figures 5 and 6).

The average fuel sulfur contents that would assure compliance with the 24-hour standard and the annual standard were derived by interpolation between test 3 and test 4 (table 2). The average fuel sulfur contents for the 24-hour compliance case are more restrictive than for the annual case. To assure compliance with both 24-hour and annual standards, a set of alternatives that establishes compliance with the 24-hour standard must be selected.

In order to place into perspective the cost of implementing each strategy, a brief economic analysis was prepared. Generally, the economic impact of implementing a given control strategy will depend on the number of affected fuel oil users, the affected volume of oil consumption, and the reduction in fuel sulfur content required. The economic analysis prepared here accounts only

Table 2.—Predicted peak annual concentrations at monitoring sites

Site	Annual concentration
	$\mu g/m^3$
Jack Junior High School	46
Lyseth School	12
Portland Jetport	15
South Portland High School	25
South Maine Vocational Training Institute	35
Portland High School	72
Masonic Building	97
Mobile Van (Downtown Location)	66
Stroudwater (S.D. Warren)	22
Warren Avenue (S.D. Warren)	13

for the differential cost between fuel of the current and required sulfur contents.

This economic analysis does not account for the expenses that might be incurred if changes to the present boiler configurations are required. Nor does it include any of the other expenses that might be required as a result of implementing the proposed alternative control strategies. The analysis also assumes that sufficient oil of the required sulfur content will be available for fulfilling the needs of the selected strategy.

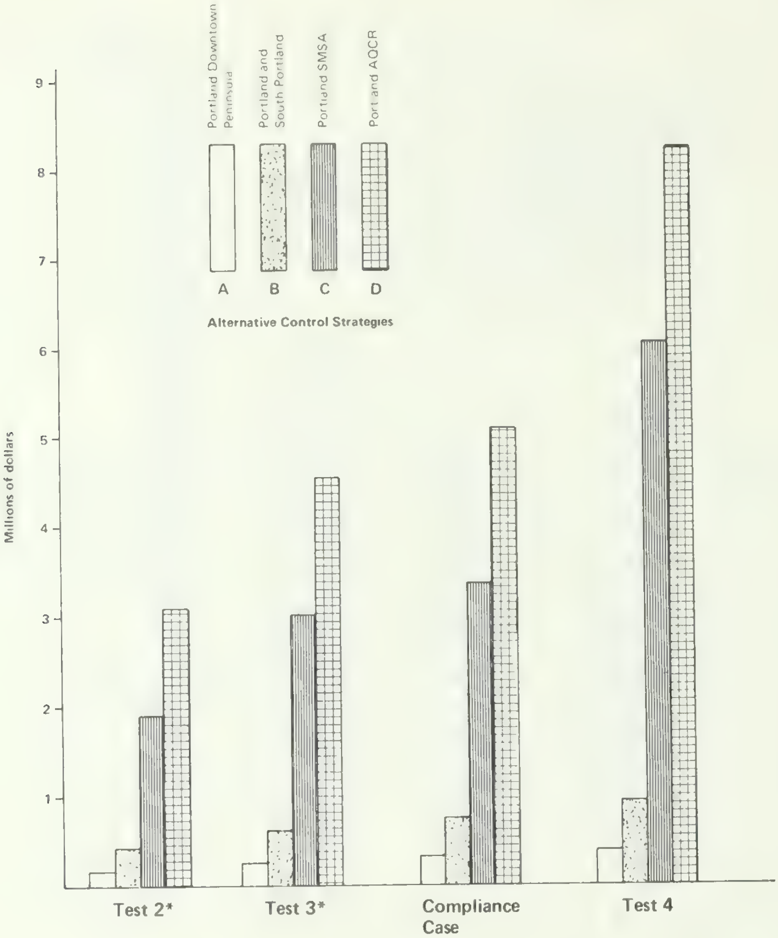
The 24-hour test case was shown to be the limiting case in terms of compliance with state standards. The economic analysis was therefore established for the average sulfur content of fuel oil specified by the 24-hour case. The annual case was not considered because less stringent reductions in fuel sulfur content were required for assuring compliance with state standards.

The results of the economic analysis per test case and alternative strategy show that costs increase dramatically as fuel sulfur level decreases and the area of control or volume of fuel affected increases (fig. 7). Test 1 is not included because it represents the status quo and no expenditures would be required. Tests 2 and 3 show costs increasing as fuel users in the Portland AQCR are subjected to increasingly stringent controls on fuel sulfur content. However, these tests are unacceptable in terms of meeting state sulfur dioxide standards. Test 4 was shown to be overrestrictive in regulating the fuel sulfur content in meeting ambient-air quality standards.

The compliance case, intermediate to tests 3 and 4, restricts fuel sulfur content only to the degree required to achieve compliance with the state standard. A comparison of the incremental costs for implementing each of the four alternatives in the compliance case shows that alternative A is the least expensive. The total incremental annual cost for implementing this strategy would be an estimated $330,000.

The results of this study and their analyses were presented at a hearing before the Maine Board of Environmental Protection. Subsequent to the hearing, the Board promulgated a new strategy for meeting sulfur dioxide ambient air quality standards in the Portland AQCR. The Board established a subregion within the original Metropolitan Portland AQCR, denoted as the Portland Peninsula Air Quality Control Region. Included in this subregion are all monitoring locations where violations had occurred. The fuel used in the subregion after 1 November 1975 was restricted to a maximum sulfur content of 1.5 percent, and the remainder of the Metropolitan Portland AQCR was per-

Figure 7.—Incremental annual costs associated with 24-hour test sequences for alternative control strategies.



*Unacceptable because predicted concentrations do not comply with standards.

mitted to use fuel with a sulfur content not exceeding 2.5 percent. The action of the Board indicates a consideration of several alternative strategies, and the final selection was based on economics and fuel supplies as well as assuring compliance with standards.

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Fugitive Dust from Vehicles Travelling on Unpaved Roads

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ABSTRACT.—A model has been developed for estimating concentrations of fugitive dust downwind of an unpaved road within a factor of 2 for most cases. The model allows for winds oblique to the road and also for extraction of fugitive dust from the plume as it diffuses to the ground. Experiments were performed to determine the accuracy of the model in estimating downwind concentrations of fugitive dust generated by a vehicle travelling on a gravel road.

AN OFTEN NEGLECTED factor that contributes to the inadequacy of a region's air is fugitive dust. Fugitive dust is defined as any solid particulate matter that does not come from a stack or flue. It contributes to particulate concentrations in several Air Quality Control Regions that still exceed the National Ambient Air Quality Primary and Secondary Standards *(Environmental Protection Agency 1974).*

There are several sources of fugitive dust in the urban environment:

1. Unpaved surfaces of travel; for example, roads, private driveways, and parking areas.
2. Paved roads, which yield a fine dust as their surfaces wear.
3. Building construction and demolition.
4. Highway construction and repair.
5. Tire and brake-lining wear.

By far the most significant contributor of fugitive dust to the total suspended particulate burden is vehicular travel on paved and unpaved surfaces. This paper is concerned solely with the prediction of fugitive dust concentrations downwind from unpaved roads, although the principles are applicable also to paved roads.

THE PREDICTIVE MODEL

As a vehicle travels over an unpaved surface, dust is elevated by two mechanisms. First, dust adheres to the tire as the tire rolls over the unpaved surface; the dust is then detached from the tire by centrifugal force and entrained in the turbulent wake of the vehicle. Second, turbulent eddies created by the passage of the vehicle sweep the fine dust from the ground and mix it upward. Both of these mechanisms cause the vehicle-road interaction to be a source of fugitive dust.

To develop an easy-to-use predictive scheme for estimating concentrations with reasonable accuracy, this source has been theoretically modeled as an elevated continuous line source of infinite extent. The assumptions inherent in this model are:

1. The particles distribute themselves in a Gaussian fashion in the vertical direction.
2. The fugitive dust is small enough that it moves exactly as the air.
3. The unpaved road is heavily travelled so that the generation of dust by traffic can be treated as a source that does not vary with time.

4. The wind speed and direction are not a function of height above the ground.
5. The car velocity greatly exceeds the wind velocity so that a line source essentially parallel to the road is generated.
6. The distance from the road at which concentrations are predicted is sufficiently small in comparison to the length of the road so that the road can be modeled as a line source of infinite length and end effects can be neglected.
7. The airborne fugitive dust particle-size distribution is such that it can be represented as a monodispersoid.

Fugitive road dust can be injected into the atmosphere continuously or instantaneously. A single vehicle travelling on a road at a speed much greater than the wind speed can be viewed as an instantaneous line source. On the other hand, many closely spaced cars travelling over the road can be modeled as a continuous line source.

Because the road dust is first of all mixed upward by the vortices trailing behind the moving vehicle, the vehicle-road interaction can be modeled as an elevated continuous line source. The turbulent wake region can be modeled as a volume of constant concentration called the mechanical mixing cell *(Beaton et al. 1972)*. Beaton references work by Eschenroder as the basis for the statement that the height of the mixing cell is approximately twice the height of the vehicle. The width of the cell is assumed to be the shouder-to-shoulder distance across the road, provided this distance is less than 30 feet. In an effort to develop a simplified model, the mixing cell, which is actually a volume source of dust, is modeled as a line source elevated to the height of the volume source and located above the center line of the road.

The conventional equation *(Turner 1970)* for describing the concentration downwind from a continuous line source of infinite extent emitting a dust plume that expands in a semi-infinite medium is

$$c = \frac{Q_T}{u \cdot \sin\theta \cdot \sqrt{2\pi} \cdot \sigma_z(x)} \left\{ \exp\left(-\tfrac{1}{2}\left(\frac{z-h}{\sigma_z(x)}\right)^2\right) + \exp\left(-\tfrac{1}{2}\left(\frac{z+h}{\sigma_z(x)}\right)^2\right) \right\} \quad [1]$$

where

c = Concentration (g/m^3)
u = Mean wind speed (m/s)
Q_T = Total line source strength as measured at the road (g/m-sec)
θ = Angle between the wind vector and the road (degrees)
σ_z = Vertical dispersion parameter (m)
z = Height above ground (m)
x = Distance downwind of the source (m)
h = Height of the source above ground (m) $= 2 \cdot V_H$ (m)
V_H = Vehicle height (m)

This model is designed to allow for diffusion in an oblique wind and to neglect particulate settling (assumption 2).

Equation 1 can be further refined by allowing the ground to adsorb any particulate matter that diffuses to the surface. A model was proposed *(Johnstone 1949)* that postulated an infinitely thin layer at the earth's surface into which particles that diffused would be adsorbed. The adsorption process was modeled as a function of the Stokes terminal velocity of the particle, which is calculated by equating the drag and gravitational forces on the particle. To allow for this subtraction of particulate matter from the plume, an image source was postulated that emits less particulate than the image in equation 1. This was achieved by placing a deposition coefficient (α) before the image term as follows:

$$c = \frac{Q_T}{u \bullet \sin\theta \bullet \sqrt{2\pi} \bullet \sigma_z(x)} \left\{ \exp\left(-\tfrac{1}{2}\left(\frac{z-h}{\sigma_z(x)}\right)^2\right) + a \bullet \exp\left(-\tfrac{1}{2}\left(\frac{z+h}{\sigma_z(x)}\right)^2\right) \right\} \qquad [2]$$

Equation 2 contains two unknowns, a and c; and thus another relationship is needed. Johnstone postulated that the second relationship should be the continuity equation

$$Q_T = {}_0\int^x V_s \cdot c\,(x', 0)\, dx' + {}_0\int^\infty \bar{u}_\perp \cdot c\,(x', z)\, dz \qquad [3]$$

where

$u_\perp$ = The mean wind perpendicular to the road (m/sec)

x' = A dummy variable representing downwind distance (m)

V_s = The particle terminal velocity as determined by the Stokes equation (m/sec)

Equation 3 states that the total mass emitted from the source equals that which has diffused to the surface up to a distance x plus that which passes through a semi-infinite plane beginning at the ground and at a distance x downwind from the road.

Four factors must be known to solve equations 2 and 3 simultaneously. First, the mean wind speed and direction must be known at the site of the unpaved road. This must be obtained either by measurement or by review of climatological data. Second, the source strength must be known. The source strength can be defined as follows:

$$Q_T = E_T \times f \qquad [4]$$

where

E_T = Total emission factor measured at the road (g/vehicle-meter)

f = Frequency of vehicle passage (vehicle/sec)

A useful estimate of the total emission factor has been obtained *(Roberts 1973)* for speeds from 10 to 30 mph on paved and unpaved surfaces (table 1). Third, the vertical dispersion must be acquired. The Pasquill-Gifford curves *(Turner 1970)* can be utilized for this purpose. Finally, the particle fall velocity must be attained. From measurements we have made, distributions of fugitive dust from gravel roads (density of limestone = 2.7 g/cc) have yielded an average number geometric mean diameter for fugitive dust of 1.6 micrometers, with an average standard deviation of 2.9. Representing the polydisperse aerosol as a monodispersoid with a diameter of 1.6 micrometers, the Stokes fall velocity can be calculated.

Table 1.—Emission factors for fugitive dust from vehicle-road interactions (Roberts 1973)

Vehicle speed (mph)	Type of road	LBS/VM* total particulate	LBS/VM below 10 microns	LBS/VM below 2 microns
10	Gravel road	3.5	0.58	0.10
20	Gravel road	7.0	1.9	.24
30	Gravel road	22.2	9.0	.77
20	Dusty paved road, no curbs	.83	.17	.022
20	Paved road with curbs, flushed weekly swept biweekly	.14	.0055	—

*LBS/VM=pounds mass per vehicle mile.

Figure 1.—A comparison of the theoretical versus experimental results on 6 August at 18.3 m from the road.

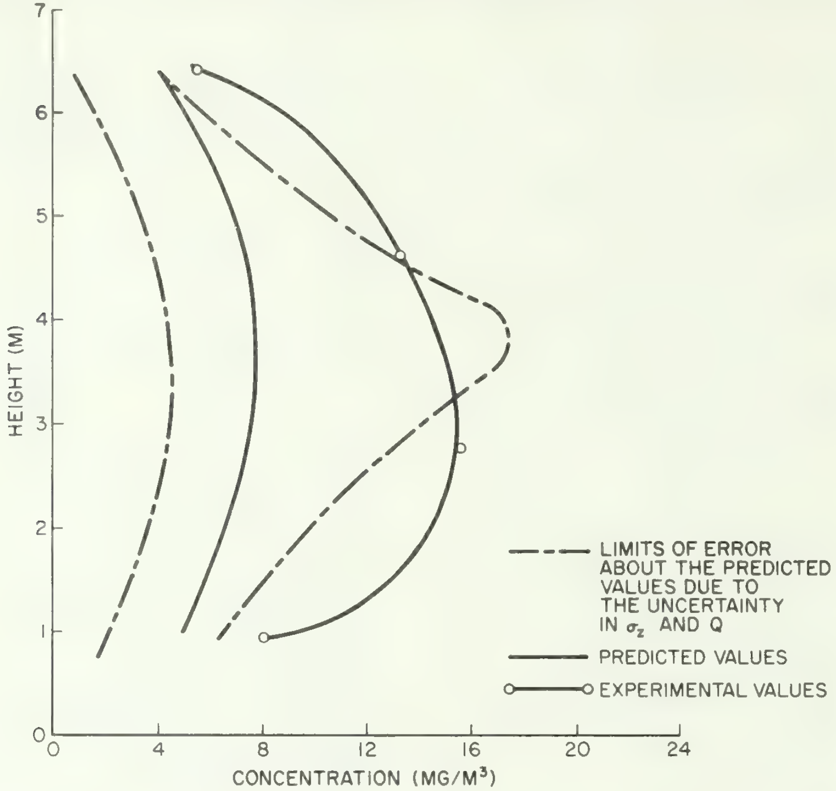


Figure 2.—A comparison of the theoretical versus experimental results on 6 August at 36.6 m from the road.

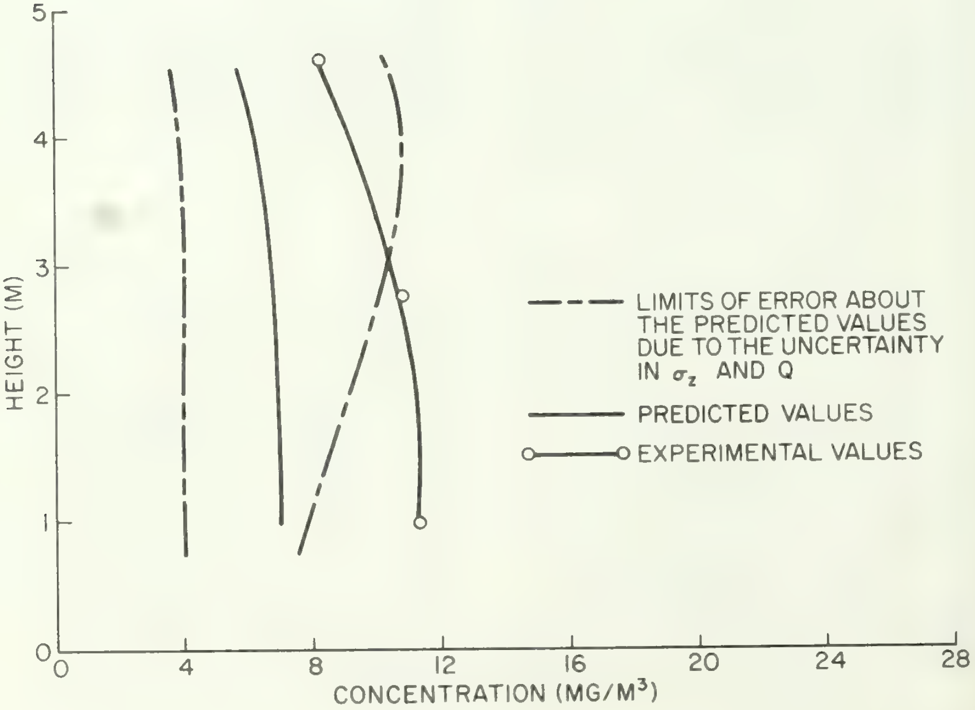


Figure 3.—A comparison of the theoretical versus experimental results on 15 August at 18.3 m from the road.

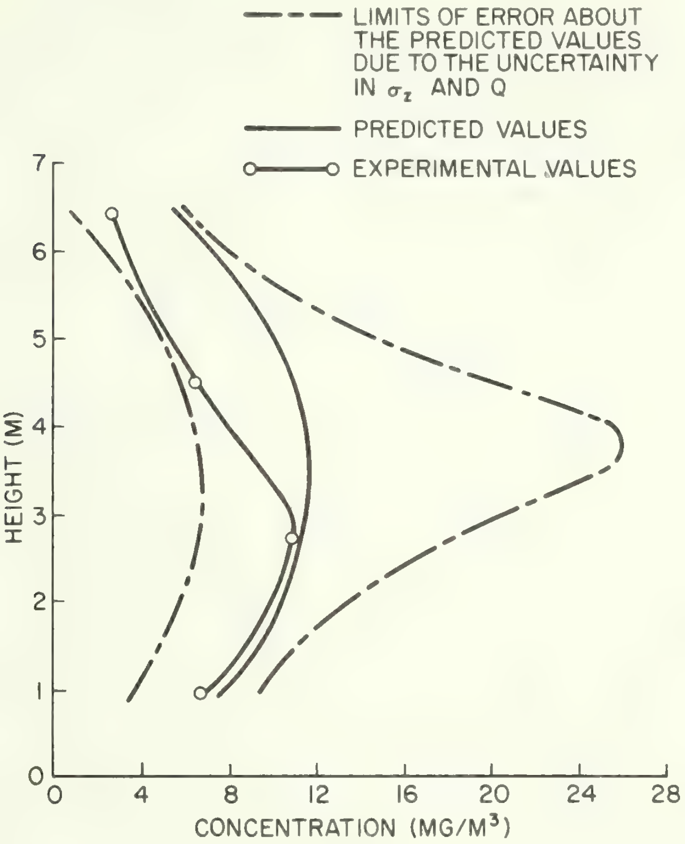
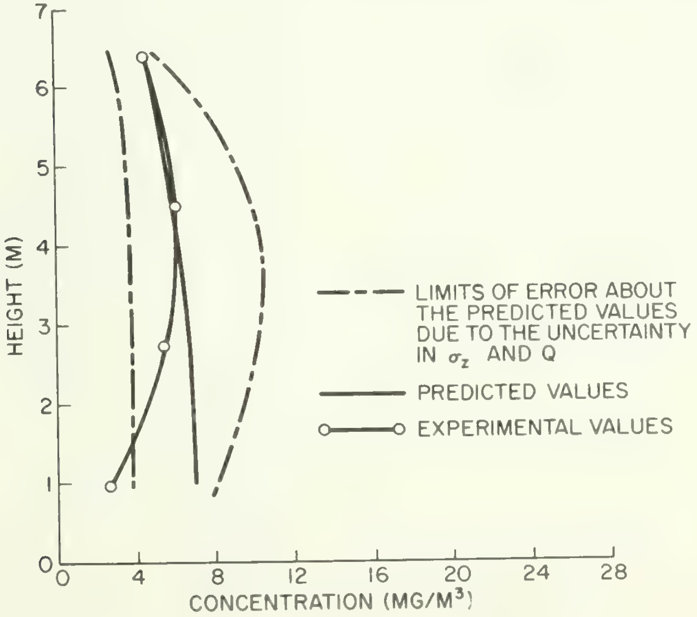


Figure 4.—A comparison of the theoretical versus experimental results on 15 August at 36.6 m from the road.



EXPERIMENTAL VERIFICATION OF THE PREDICTIVE MODEL

To test the validity of the predictive model, an experiment was designed to sample the dust cloud generated by a vehicle travelling on a gravel road. A 1000-foot straight section of gravel road giving access to farm lands provided the fugitive dust source. A vehicle of height equal to 6 feet travelled the road at a controlled speed of 30 mph and a frequency of two passes per minute. A classification of the gravel size was determined by sieving. The maximum size stone comprising the road was ½ inch, and 3.7 percent of the total sample mass was particles of less than 88 micrometers.

The dust plume was sampled in a plowed field downwind from the road. Concentrations in the plume were obtained at a fixed distance downwind by open-faced filters mounted at four elevations above the ground on a stationary support. Two vertical concentration profiles were attained on 6 August 1974 at 18.3 m (60 feet) and at 36.6 m (120 feet) downwind from the road. Again on 15 August, two vertical profiles were obtained at the same downwind distances. The samples were drawn for 10 minutes at 3.5 1pm on 6 August and for 20 minutes at 7.7 1pm on 15 August. Both sampling days could be classified as B stability with wind speeds of 2 m/sec.

A comparison of the concentrations as estimated with Equations 2 and 3 and the experimentally measured concentrations, both at the above given conditions, was made for all four experimental profiles (fig. 1 to 4). The predicted concentrations were found to be within a factor of 2 for 11 of the 15 measurements and within a factor of 3 for all measurements. The combined limits of accuracy suggested for σ_z *(Turner 1970)* and for the emission factor *(Roberts 1973)* accounted partially for the variation between experiment and theory. Turner suggested that σ_z may be expected to be correct within a factor of 2 in all stabilities provided one was only considering diffusion within approximately 200 m of the source. Roberts reported a mean emission factor of 9 pounds/vehicle-mile with a 95-percent confidence interval from 8 to 10 pounds/vehicle-mile. Thus, the source strength in the predictive model had an error band of ±1 pound/vehicle-mile times the frequency of vehicle passage. The theoretical bands of error due to the uncertainty in both σ_z and Q are also portrayed in figures 1 to 4.

APPLICATION OF THE PREDICTIVE MODEL

Equations 2 and 3 were solved simultaneously under selected conditions (fig. 5 and 6). Figure 5 portrays the variation with x of the concentration at a height of 2.7 m for various wind-road angles. Two important conclusions can be drawn. First, the effect of wind-road angle on the downwind concentration under the given meteorological conditions and for the given aerosol parameters was negligible beyond 100 m. Second, up to 100 m from the road, the concentration increased as the wind direction shifted from perpendicular to parallel to the road. Figure 6 shows the variation with x of the concentration at a height of 2.7 m, given various particle sizes. The conclusion to be drawn from this graph is obvious. The concentration decreases with x more rapidly as the particle size increases. In terms of deposition, the above result can be understood by considering that larger particles are removed from the plume at a more rapid rate than smaller particles.

CONCLUSION

The predictive model yields concentrations within a factor of 3 of the actual concentrations. Given the meteorological conditions, a highway engineer or air-pollution engineer concerned with the local effect of a proposed unpaved surface on local inhabitants can use equa-

Figure 5.—The variation of concentration with distance perpendicular to the road for various wind-road angles.

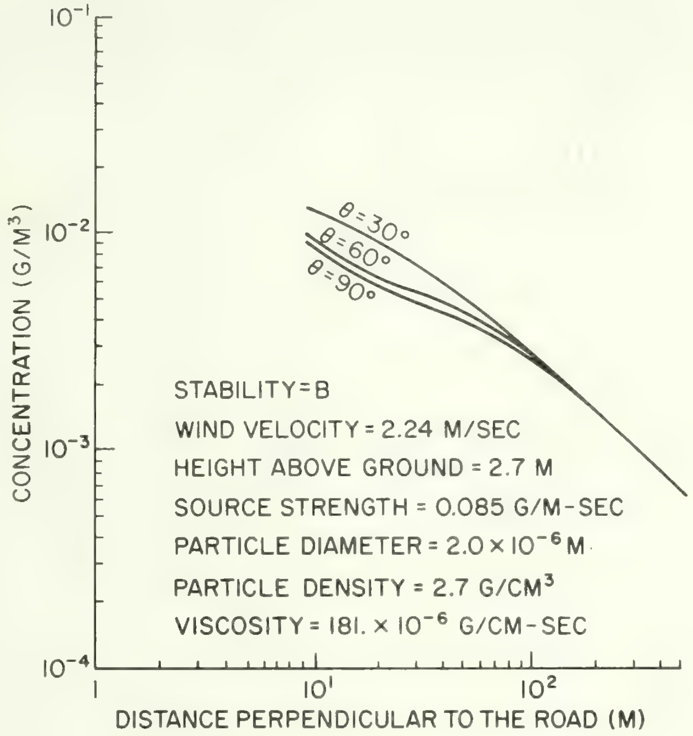
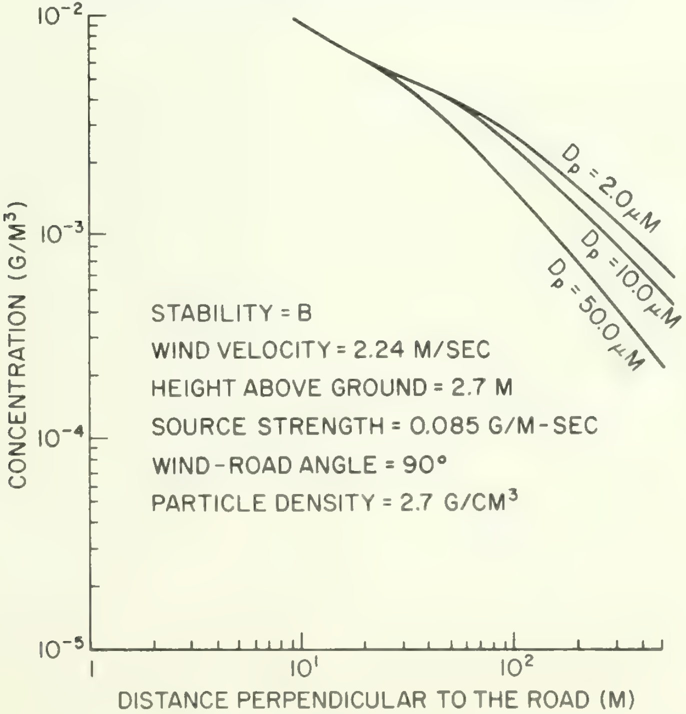


Figure 6.—The variation of concentration with distance perpendicular to the road for various particle sizes.



tions 2 and 3, along with Robert's total emission factors, to determine whether detrimental particulate concentrations might exist. Furthermore, this method can be applied just as readily to fugitive dust from paved surfaces. Roberts determined an emission from a paved surface travelled by a vehicle at 30 mph. More extensive research on emission factors from paved roads and at different vehicle speeds is needed before extensive application of this model can be made to paved surfaces.

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VEGETATION AND AIR QUALITY

Air Quality as Reflected by Injury to Metropolitan Vegetation

by A. F. RHOADS *and* E. BRENNAN, *graduate student and associate research professor, respectively, Department of Plant Biology, Cook College, Rutgers, The State University of New Jersey, New Brunswick, N. J. 08903.* *This is a paper of the Journal Series, New Jersey Agricultural Experiment Station, Cook College, Rutgers University. This research was supported by funds provided by the Northeastern Forest Experiment Station through the Pinchot Institute for Environmental Forestry Research, Consortium for Environmental Forestry Studies.*

ABSTRACT.—Chemical monitoring is the classical way of defining air quality. However, the ability of plants to reflect changes in air quality must not be overlooked because certain species respond in definite ways to gaseous pollutants. In New Jersey, chemical-monitoring data and plant-injury data have proved supportive for SO_2. While oxidant concentrations seemed to agree with plant data, recent changes in monitoring procedures have made the relationship unclear. Plant data have provided the only evidence for the presence of toxic amounts of fluoride in the air and have warned of the existence of as yet unidentifed substances that impair air quality.

EVALUATION OF AIR QUALITY of an urban environment can be ased on two criteria: chemical data obained by standard monitoring proedures and biological data collected in ealth and vegetation studies. Ideally, or each pollutant one would like to now the concentration present in the mbient air and the response that it licited in a sensitive receptor, be it uman or plant. Having been concerned ith both types of evidence in New ersey, we will discuss three kinds of ituations we have encountered.

Before we do this, it might be apropriate to indicate just how urban an nvironment New Jersey is. The Garden tate has a modest area of 7,836 square iles and a population of more than 7 illion people squeezed into it — a density of 953 people per square mile, the highest in the Nation. The number of registered motor vehicles is more than 3.5 million, a density of 492 per square mile.

SULFUR DIOXIDE DATA IN AGREEMENT

The first situation is one in which monitoring data for the concentration of a pollutant in the ambient air are in agreement with plant-injury observations, and this involves sulfur dioxide (SO_2).

Sulfur dioxide has a long history of damage to vegetation in many parts of the United States. The major sources of SO_2 emissions in New Jersey are shown in table 1. However, since 1968 New Jersey has had in effect regulations

Table I.—Sources of SO_2 emitted into the air in New Jersey in 1970

Source	Proportion attributed
	Percent
Power plant fuel	45
Commercial and industrial fuel	27
Residential fuel	12
Manufacturing processes	9
Transportation	6
Incineration	1

Source: New Jersey Department of Environmental Protection.

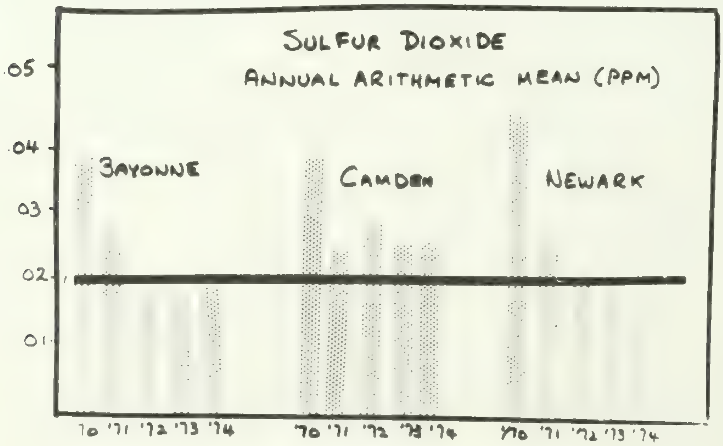
controlling the sulfur content of fuels used in the State. These regulations have been very effective in reducing SO_2 content of the air, as can be seen in the figures from the New Jersey Department of Environmental Protection Air Monitoring System for three locations in the State (fig. 1). Ambient SO_2 concentrations are now at or below the federal standard of 0.03 ppm maximum annual average. In the 2½ years during which we have been conducting a state-wide survey of air-pollution damage to woody plants, SO_2 injury has been notable for its absence.

Even when we made it a point to visit the site of power-generating stations, some of which burn coal and some oil, we were unable to find SO_2 damage on normally sensitive plant species such as crabapple *(Malus sp.)*, birch *(Betula spp.)*, zinnia *(Zinia elegans)*, tomato *(Lycopersicon esculentum)*, blackberry *(Rubus spp.)*, and white pine *(Pinus strobus)*. Inspection trips were made to the vicinity of six power plants in June 1974 and two others in July 1975. These stations were located in urban, relatively suburban and rural settings. The only site where probable SO_2 injury was observed was in northwestern New Jersey at a Christmas tree plantation 1½ miles downwind of a Pennsylvania power-generating station. Pennsylvania hasn't as rigid restrictions on sulfur content of fuels as New Jersey. It remains to be seen what will happen in terms of plant damage now that economic pressures have forced a relaxation of the regulations in New Jersey. At this time we can conclude that the chemical and biological data in respect to SO_2 are supportive.

OZONE-OXIDANT SITUATION UNCLEAR

Until 2 years ago we would have stated that the data for oxidant concentrations and plant damage are generally in agreement. Air-quality

Figure 1.—Ambient SO_2 concentrations (annual mean) in three New Jersey cities, 1970-74. Source: New Jersey Department of Environmental Protection.



standards for ozone were established in 1970 at 0.08 ppm as an maximum hourly average based on data obtained with the Mast (Mast Development Co., Davenport, Iowa) total oxidant meter. In New Jersey we have consistently observed ozone damage on sensitive species such as bean and tobacco following elevated Mast readings. A study conducted simultaneously at several locations in the Northeast attempted to correlate Mast total oxidant-monitoring data with injury to ozone-sensitive Bel W-3 tobacco *(Jacobson and Feder 1974)*. Although there were some variations, generally the most severe tobacco injury occurred at the sites that also had the greatest number of high Mast readings. However, recent changes in the monitoring technique required by the Environmental Protection Agency (EPA) have complicated the picture.

EPA has specified a chemiluminescent procedure as the required method of ozone monitoring. Unlike the Mast meter, it is specific for ozone, the major component of the total oxidant complex. Since New Jersey air-monitoring facilities replaced Mast meters with chemiluminescent devices in 1973, the apparent ozone level in ambient air has increased. This increase has not been accompanied by a discernible increase in plant injury. As far as we know, no one has systematically compared ozone levels obtained by a chemiluminescent technique and plant response. Until this is done, we will not know the significance of the data in terms of effects on sensitive plant species. Since primary and secondary air-quality standards are based on effects on human health and plant life or property, respectively, it would seem of the greatest importance to resolve this matter as soon as possible and establish new standards based on new monitoring technology if that proves necessary.

Meanwhile we do have evidence from our observations of sensitive plant species that an ozone problem exists in New Jersey, whatever the magnitude of the concentrations. Plantings of beans at New Brunswick and the Rutgers South Jersey Research Center in 1974 and 1975 provide ample evidence of damaging levels of ozone. Ozone fleck on white pine also occurs throughout the State. In addition, we commonly observe a dark upper-surface stipple on ash *(Fraxinus americana)*, zelkova *(Zelkova serrata)*, dogwood *(Cornus florida, C. stolonifera)*, and linden *(Tilia tomentosa, T. europaea, T. enchlora)* developing in midsummer. This symptom is similar to ozone toxicity symptoms on herbaceous species such as bean. However, more experimentation is necessary to determine to what extent ozone or other stresses are involved in this symptom development.

Further controversy has recently been injected into the ozone-oxidant picture with the finding that certain remote rural sites show surprisingly high ozone levels. Various hypotheses, including natural sources, long-distance transport from urban areas, and consumption of ozone in urban atmospheres, have been proposed to account for these high levels. Again a correlation with plant injury is lacking. Simultaneous observations of sensitive plants could help to clarify the significance of these monitoring data. With ozone we therefore have a situation where there is a demonstrated need for the simultaneous collection of monitoring data for pollutant concentration as determined by chemiluminescent procedures and of plant-injury data.

PLANTS LEAD THE WAY

The third type of situation is the case where injury to plants is our only definitive clue to the presence of injurious substances in the air. Hydrogen fluoride (HF) is a case in point. The New Jersey Department of Environment Protection does not monitor HF because the state has not established standards for atmospheric fluorides. Statewide surveys of air-pollution damage to agronomic crops conducted in 1971 and 1972 showed HF damage amounting to 3 percent and 18 percent of the total losses, respectively *(Feliciano 1971, Pell 1973)*. Characteristic HF damage to woody and herbaceous plants continues to reflect the presence of toxic levels of this pollutant. In 1974 HF was the major cause of air-pollution damage to woody vegetation in the state *(Rhoads and Brennan 1975)*. Fluoride injury appeared as marginal scorch on a variety of species, including gladiolus, *(Gladiolus* hyb.), wild cherry *(Prunus virginiana)*, grape *(Vitis labrusca)*, linden *(Tilia americana)*, blueberry *(Gaylussacia spp.)*, and aspen *(Populus tremuloides)* and as tip necrosis of various coniferous trees. Even oaks *(Quercus alba, Q. velutina,* and *Q. prinoides)*, which are considered only moderately sensitive to fluorides, were severely injured. Trees showing resistance during this extreme episode included *Acer platanoides, Ilex opaca, Malus* spp., and *Betula populifolia*. Tissue analyses of leaf samples collected in the affected area helped to pinpoint atmospheric fluorides as the cause of the injury, and gave homeowners whose plants had been affected the local industrial sources. Unfortunately it is not possible to make a quantitative estimate of ambient HF concentrations from tissue fluoride levels. Monitoring procedures for the pollutant must be initiated.

UNKNOWN POLLUTANTS

We have encountered another type of situation where we have neither chemical air-monitoring data nor specific plant data. We know that plants are being injured by some air pollutant, but we do not know its identity. One case involves a distinctive tip injury on Austrian pine *(Pinus nigra)* which is always delimited by a dark band at the base of the necrotic area *(Brennan and Davis 1967)*. This symptom occurs on certain sensitive trees year after year, with varying severity. Other neighboring trees are consistently resistant to whatever the causal factor is. We have evidence for an atmospheric cause of the Austrian pine tip-burn symptom as a result of the use of two open-top air-pollution modules, one supplied with charcoal-filtered air and the other with unfiltered ambient air *(Mandl et al. 1973)*. Using grafted trees prepared from scions of mature Austrian pines showing sensitivity and resistance to this sympton, we have shown that the incidence of tip burn was much greater on the sensitive grafts grown in the unfiltered module than on those in the filtered module or on the resistant grafts. We have been unable to duplicate this symptom through controlled fumigations with O_3, SO_2, or a combination of O_3 and SO_2. The combination approximates the symptom, but the dark band does not become evident until 3 or 4 weeks after fumigation.

In summary, we emphasize the necessity of using both chemical monitoring devices and biological systems to evaluate air quality. Chemical monitoring alone may yield data on ambient levels of many different pollutants. However, unless we can relate these levels to effects on receptors, they are meaningless abstractions. Plants alone are not a satisfactory monitoring system, for although most pollutants elicit a characteristic response, it is too easily affected by other environmental variables *(Pell and Brennan 1975)*. Our observations in New Jersey indicate that, at present, monitoring data and plant effects are well correlated in the case of SO_2. The ozone-oxidant situation is not as clear. Recent mandated changes in monitoring techniques require a reassessment of the degree of plant injury associated with certain ozone levels. In the third instance we find plant data yielding information about a pollutant, HF, which probably should be included in a monitoring program. And finally, we see reflected in vegetation the presence of s yet unidentified chemical substances 1 the atmosphere that are indicative of urther impairment of air quality.

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Sulfur Pollution : An Environmental Study of Welland, Ontario

by MICHAEL R. MOSS, *assistant professor, Department of Geography, University of Guelph, Guelph, Ontario, Canada.*

ABSTRACT.—The distribution of sulfur as an environmental pollutant is analysed in the vicinity of Welland, Ontario. A biogeochemical-cycle approach enables areas of excess accumulation to be compared among all linked ecosystem components. Although the patterns of distribution are similar, the amounts of sulfur accumulated in different ecosystems, grassland and woodland, show marked contrasts. The significance of these findings to urban and rural land-use planning is considered.

THE PAST DECADE has produced a tremendous explosion of information about all aspects of pollution. In spite of this there seems to be a major gap in our knowledge or an inability to apply our knowledge of the effects of pollutants within a total environment. This is particularly true in terms of terrestrial environments, yet there is a large volume of material on the effects of individual pollutants upon the separate components of these environments.

Although environment-impact statements are often a prerequisite for planned development of the human environment, the spatial impact of pollution upon the environment is often neglected. With the current rapid rate of urban growth in such places as southern Ontario, the impact of the urban physical environment system upon rural areas will undoubtedly increase.

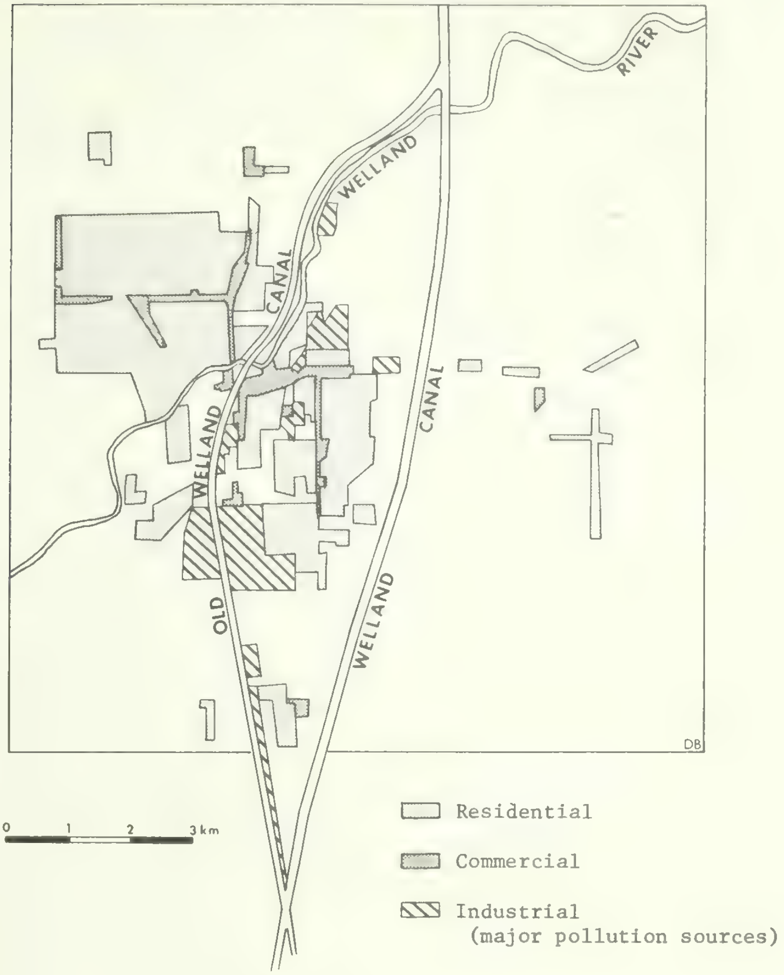
This impact will be most evident in the rural/urban fringe areas of existing urban centres. Yet it is also in these fringe areas that there will be the greatest demands for residential expansion, recreational facilities, and improved standards of environmental quality. This is a report on an attempt to identify the impact of one pollutant, sulfur, upon the total physical environment of Welland, Ontario, and to show how an integrated approach to such a problem can benefit the planning of urban expansion and amenities in the surrounding area.

THE AREA

The city of Welland, Ontario, and its immediate hinterland provide an ideal site for a spatial impact study. Welland is a moderate-size urban center (population about 50,000), which is heavily industrialized, having several major steel-producing and metallurgical industries centrally located in an elongated belt paralleling the Old Welland Cana (fig. 1). Furthermore, the city is sufficiently isolated from other major urban/industrial centers such as Hamilton Ontario (48 km northwest) and Buffalo New York (24 km east) to remain reasonably free from any influence from such centers. The Welland area also lacks any major topographic barriers – being located on the Haldimand Clay Plain and at a point sufficiently fa inland to avoid any significant lake breeze effects from either Lake Erie (1 km south) or Lake Ontario (22 km north).

It is an area of declining agricultura importance, yet there remain severa viable truck farming operations to th northwest. Soils are generally rathe poorly drained clays, clay loams, an silty clay loams. Locally they are low quality soils, but in a broader regiona or national context they are classed a

Figure 1.—The city of Welland, Ontario, showing the distribution of major urban land-use types.



oils with only moderate limitations to heir future re-use and are therefore of easonable potential.

Residential expansion is currently hrusting in a northward direction, but urther expansion is likely to be to both ast and west of the built-up area. Ribon development is now a common ature along many of the rural roads, nd increasing housing demands within e region will no doubt heighten the roblem.

Furthermore, to accommodate this ex- nding urban population, the area (fig. contains five separate locations with high recreational potential, three areas that are unique biological sites, and the banks of the Welland Canals with their recreational potential *(Philips Planning and Engineering 1971a)*.

Planners of human space and environmental quality should be aware of the condition of the physical environment because this will directly affect the amenities outlined above. Since all these amenities are themselves components of the environmental system, it follows that man's impact upon this system (in this case as pollution) should be undertaken from the point of view of a system analysis of the total environmental system. This can be achieved through an ecosystem analysis.

THE APPROACH

An ecosystem approach should provide the most substantial and meaningful studies of environmental pollution *(Moss 1976)*. In this way the biogeochemical cycles, which are a natural functioning part of any ecosystem, can be used as models that naturally perform an integrative function in linking all environmental components. Excess quantities of any biogeochemical element that can be shown to disrupt the normal functioning of any ecosystem can be said to be pollutants. In addition, the biogeochemical cycles provide the necessary information about the precise form of the pollution element to be measured in any one ecosystem component.

By the established pathways taken by such elements, the links from component to component can be identified. At the same time a knowledge of the normal concentration of each element in each component can be used as a measure against which excess concentrations may be noted. It is the effects of such excesses that are considered pollution. Measurement of the distribution of concentrations would therefore identify the spatial impact of a pollutant upon an area.

SULFUR IN THE WELLAND ENVIRONMENT

The approach outlined above will identify the sulfur cycle as a pollution model to be utilized in an environmental context. In almost every ecosystem, sulfur is made available quite naturally either by weathering of bedrock or by absorption of gaseous sulfur from the atmosphere. This system is disrupted in locations where excess amounts of sulfur are injected into the atmospheric component, primarily as SO_2, as a result of fossil fuel combustion and industrial processes. This may be viewed in ecosystem terms as a new pathway introduced into the sulfur cycle, that is, sulfur from the lithosphere reaching the biotic component via the atmosphere in much greater quantities and over a much shorter time span than it possibly could under natural circumstances *(Moss 1976)*.

The sources of excess sulfur in Welland are primarily industrial (fig. 1). In 1968 (the last year for which complete data are available) some 1903 tons were injected into the atmosphere. Of this total, 1,701.5 tons were emitted by industrial sources *(Ont. Dep. Energy and Resour. Manage. 1968)*. This survey of atmospheric sulfur was conducted for March through June, using 20 sites within the built-up area. The results obtained by the lead-peroxide method show a change from winter to summer concentrations with values as high as 1.20 mg SO_3/100 cm^2/day immediately to the east of the main source. More significant is the spatial pattern. In each month the highest values occur to the east, downwind of the major pollution sources. However, a secondary area of moderately high concentrations with values between 0.50 and 0.70 mg SO_3/ 100 cm^2/day is always present to the west of the Old Canal and extends over the western residential area and into the rural zone. A sharp decrease in values is encountered to the east of the main industrial zone, and a more gradua decline in values to the north and south

From September 1973 to Januar 1974, I extended the survey area, usin 15 stations primarily to the east of Welland and extending several miles int the rural area. The use of Huey plate provided data similar to that of th 1968 survey and showed the highes values obtained to be 1.22 mg SO_3/10 cm^2/day in January 1974 for the sit equivalent to that mentioned above fo the 1968 survey. Again the highest value of SO_3 were immediately east of the mai source, and values decreased at varyin rates from this peak. One major devia tion from this pattern, however, is encountered at distances approximately 4.8 to 6.4 km east of the source, where a zone of secondary concentration is encountered.

If the results of the two surveys are now combined to produce a pattern indicative of long-term conditions, then the distribution of atmospheric sulfur in the Welland area appears to be one of three fairly well defined and distinct areas of concentration (fig. 2). The most evident is the zone of high values encountered immediately east (downwind) of the major source. Here values greater than 1.00 mg SO_3/100 cm^2/day are encountered. This area is separated from the other two zones, which are due east and west, by troughs of fairly low mean values. Both secondary concentrations indicate values in the range > 0.50 to $<$ 0.75 mg/100 cm^2/day. The area of secondary concentration to the east appears to be less prominent in fig. 2. than it actually is in each month because of its north-south migration over 4.8 or 6.4 kms. at different months.

Anthropogenically - produced atmospheric sulfur has several possible fates. Some will undoubtedly drift outside the immediate area, but the natural pathway for this atmospheric sulfur is to enter the biotic component of the environment either as gaseous SO_2 absorbed by soils and vegetation or as $SO_4^{=}$ deposition, mainly in precipitation to the soil surface and subsequently to plant roots *(Moss 1976, 1975a).*

Soil samples from the A1 mineral soil horizon were collected from sites within 8.5 km of the main sources of atmospheric sulfur and were analyzed for $SO_4^{=}$ content by the barium sulfate turbidimetric technique. A total of 26 sites were used, the majority to the east of the city. When results are presented in graph form and plotted against distance from the source, some significant patterns emerge (fig. 3). The data show values to decrease with increasing distance from the source to a point about 4.0 km and then subsequently rise to a second and lower peak at about 6.4 km and then decrease. When woodland soils are distinguished from grassland soils this trend is particularly marked in woodland soils, the grasslands showing greater variation near to the source.

Figure 2.—Schematic representation of the seasonal average concentration of atmospheric sulfur over Welland and adjacent rural areas. Isolines drawn at 0.10 intervals, show SO_3/100 cm^2/day.

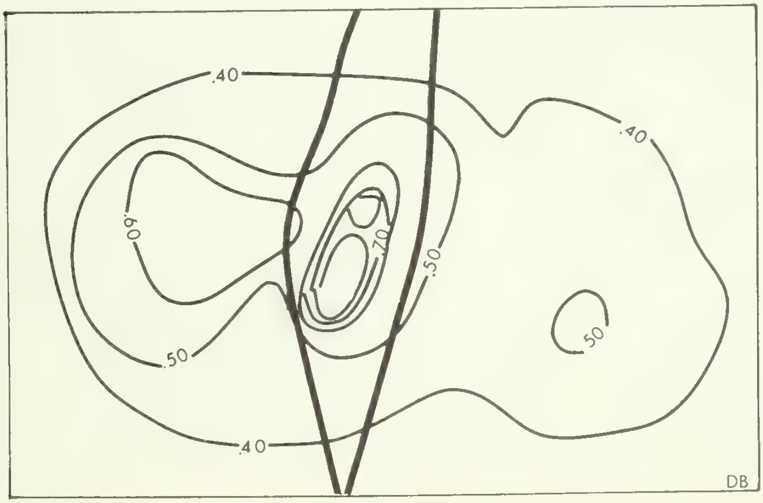
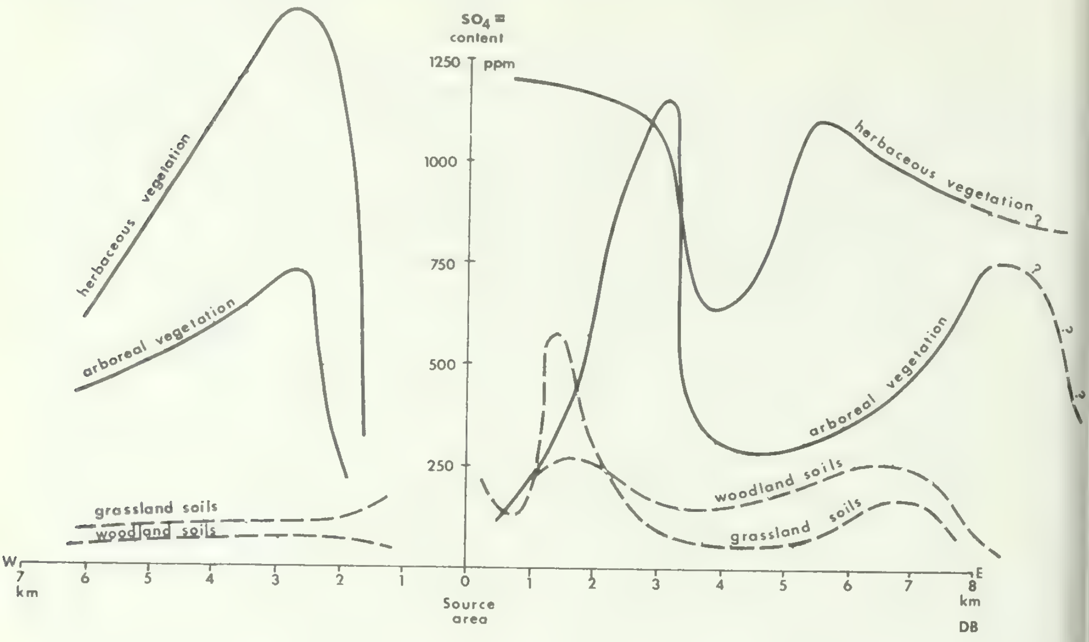


Figure 3.—The generalized distribution of sulfate in soils and vegetation samples with respect to distance from the main source area.



Data to the west are too sparse for any significant identification of trends because of fewer possible sampling points. The mean value for all soil $SO_4^{=}$ values is 134 ppm, which can be subdivided into one of 160 ppm (range 18 to 726 ppm: n=13) for grassland soils and 134 ppm (range 50 to 284 ppm: n=3) for woodland soils.

Vegetation was analyzed for $SO_4^{=}$ in related surveys, one of herbaceous vegetation growing in abandoned fields and one of leaf samples from woodland sites. The results of these analyses are included in figure 3. Complete data for both soils and vegetation and the cartographic presentation of results have been published *(Moss 1975a)*. Sites were the same as those used for soil sampling.

Herbaceous vegetation samples consisted of clippings of 1m^2 quadrats, five for each location. Every effort was made to ensure uniformity of herbaceous species and age of abandonment.

The results for herbaceous vegetation show that, except for two points about 4.0 km from the source, the amounts decrease very slightly over 8.0 km in an easterly direction. Values obtained are consistently between 1,000 and 1,280 ppm $SO_4^{=}$ except at 4.0 km, where values fall to 588 and 802 ppm. To the west, the three locations sampled indicate a rise from 267 to 1,400 ppm over 0.6 km and a drop to 527 ppm at 6.1 km.

In sampling woodland vegetation, more consistency was possible in the materials sampled. In each case oak leaves were collected. Quantities measured ranged from 190 to 1,250 ppm and, as in the case of herbaceous vegetation, the pattern to the east showed two areas of relatively high values, one centered around 3.2 km and the other around 8.0 km from the source. To the west arboreal samples show a similar pattern to herbaceous vegetation.

Comparison between the arboreal and herbaceous data sets indicates that the mean concentration in herbaceous vegetation for all sites is 975 ppm (1047 ppm to the east, 731 ppm to the west). Mean values for arboreal samples is 546 ppm for all sites (576 to the east and 472 to the west). In seven cases herbaceous and arboreal samples were collected less than 0.4 km apart, yet in five of these cases the arboreal samples showed values to be about one-half or less of the herbaceous $SO_4^=$ values.

DISCUSSION

Though it is not possible to obtain statistically valid correlations in the spatial distributions of sulfur between either the atmosphere, the vegetation, or the soil, there is a remarkable correspondence in the nature of the distributions encountered. Both ecological and pedological reasons can be advanced for this lack of statistical relationship *(Moss 1975a)*. This result, however, differs from the similar work of Johansson *(1959)* and McGovern and Balsillie *(1972)*, who were able to show a straightforward linear relationship between distance from source and atmospheric sulfur and vegetation-accumulated sulfur. Lihnell *(1969)* found a somewhat irregular pattern in his results from using similar variables. What these contrasting results do show, however, is that in many cases individual locations have to be treated independently. Although there are established functional links between all environmental components, the patterns that emerge are determined primarily by the source and the atmospheric dynamics of the site. Successive stages in the movement of the pollutant from component to component will reflect this atmospheric spatial pattern.

In the Welland case the occurrence of three distinct areas of atmospheric sulfur concentration should have direct implications for any development in areas adjacent to the present built-up area. In terms of air-quality standards, continuous monitoring for sulfur oxides at the most heavily polluted site showed that in 1973 on no occasions did concentrations exceed Ontario criteria for desirable air quality *(Ont. Minist. Environ. 1973)*. But whereas sulfur in the atmosphere is relatively short-lived and there is a constant throughput when this passes to the next component, there will be build-up. Here, in the soils and vegetation, sulfur will accumulate over a long period of time; a growing season for vegetation and longer for soils. In both of these, local variables will determine accumulations. For Welland, where the atmospheric sulfur is not severe, values of soil sulfur reach 726 ppm. This is considerably higher than any value obtained in the heavily industrial Sheffield region in England *(Moss 1975a)*. For Trail, British Columbia, a mean of 185 ppm *(Katz et al 1939)* is not appreciably different from that of 134.12 ppm for Welland. For vegetation the Welland values appear to be extremely high when compared with, for example, data from industrial South Wales, where oak leaves yielded a high of 113 ppm at 2.4 km from a source.

The significant point from the above comparisons is, that to determine areas of environmental pollution requires an initial extensive survey to determine the extent of the atmospheric sulfur pattern, even in an area of relatively uniform surface topography. The quantities of the pollutant encountered in the next environmental component should reflect the atmospheric pattern although in different localities what may be acceptable limits in one component may be quite unacceptable in another.

Furthermore, there are obvious differences between the amounts of sulfur absorbed and accumulated by soils and vegetation between grassland and woodland ecosystems. The fact that grassland ecosystems appear to accumulate more sulfur could have significant repercussions on air hygiene in the area. The planting and maintenance of sulfur-tolerant grass species could be useful in land-use planning.

CONCLUSIONS

By identifying the spatial limits of potential pollution from the first stage of environment transfer — the atmosphere — the spatial limits of potential environmental pollution are set. In this way the erroneous and restricted limits of the area affected by air pollution recognised by local planning studies as being limited to two centers between the Old and New Welland Canals would be overcome *(Philips Planning and Engineering, 1971).* Any other environmental components can only be vertically linked by the natural pathways. Differences in the reaction of these biotic components to accumulation can yield significant clues to the maintenance of viable ecosystems. Although concentrations and accumulations do not indicate pollution in the true sense, they do identify where pollution will occur. Thus the occurrence of higher values of sulfate being encountered in precipitation at 8 km from the source than at 4 km from the source, and the significance this has for precipitation pH, can be explained *(Moss 1975b).* Only by such a method can a more meaningful environmental approach to environmental planning be initiated.

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Landfill Gases and Some Effects on Vegetation

by FRANKLIN B. FLOWER, IDA A. LEONE, EDWARD F. GILMAN, *and* JOHN J. ARTHUR, *Cook College, Rutgers University, New Brunswick, N. J. 08903. Flower is extension specialist in environmental science, New Jersey Cooperative Extension Service; Leone is professor, Department of Plant Biology; and Gilman and Arthur are research assistants in Plant Biology.*

ABSTRACT.—Gases moving from refuse landfills through soil were studied in New Jersey. The gases, products of anaerobic decomposition of organic matter in the refuse, caused injury and death of peach trees, ornamentals, and commercial farm crops, and create possible hazards to life and property because of the entrance of combustible gases into residences. Remedial measures are described.

THREE REFUSE LANDFILLS in New Jersey have been under study for the past 6 years because underground gases from the landfills have been moving through the soil into adjacent areas and damaging vegetation.

The New Jersey Cooperative Extension Service, charged with responsibility for responding directly to the needs of the state's citizens, becomes involved with various kinds of problems. One of these has been the underground generation and movement of combustible gases, carbon dioxide, and the odorous gases of sulfur reduction. Although there are many different sources for these gases, we have been working with those arising from the decomposition of organic matter in commercial refuse landfills.

The members of the Rutgers-Cook College faculty who have been involved in these studies include a specialist in environmental sciences, county agents, plant pathologists, entomologists, and soil scientists. In addition, whenever possible we have involved the staffs of the state, county, and municipal health departments, the New Jersey Bureau of Solid Waste Management, the federal solid waste management programs, the owners and operators of the various refuse landfills, and the owners of the properties affected.

The problems described in this paper include the death of peach trees in a commercial peach orchard in Gloucester County, the death of ornamental vegetation in Camden County, and damage to commercial farm crops in Burlington County. All are located in the southwestern quarter of the state. In addition to the death of vegetation, the Camden County case involved a hazard to life and property because of the entrance of combustible gases into private residences adjacent to the landfill.

THREE LANDFILL CASES

The three landfill cases we have followed most extensively during the past 6 years are in Glassboro, Gloucester County; Cherry Hill, Camden County; and Cinnaminson, Burlington County. All were brought to the senior author's attention by Rutgers County Agents responding to complaints of vegetation injury and death from unknown causes. All three cases were associated with landfills where refuse had been deposited in worked-out sand and gravel pits.

Glassboro

The landfill in Glassboro covered about 6 acres. The refuse, which consisted of household and industrial wastes, demolition materials, and sewage sludge, was deposited to depths of 10 to 20 feet. A commercial peach orchard abutted the landfill along about 1,000 feet of its periphery. The balance of the landfill was adjacent to scrub vegetation on land that was apparently not serving any commercial, agricultural, or residential use.

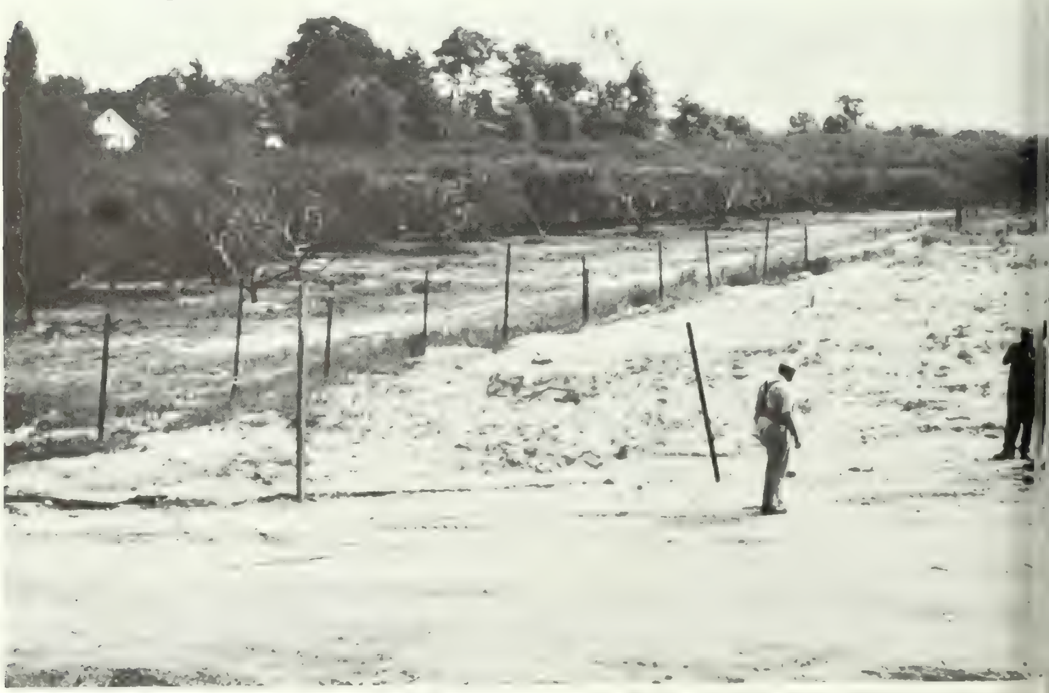
Landfilling at this site began in February 1968. Refuse deposition along the northeast line of the landfill adjacent to the peach orchard was completed in 1969. The peach trees nearest this line began dying during the summer of 1971. Our first inspection of this site was made in September 1972. By that time about 50 peach trees had died (fig. 1). Combustible gases and carbon dioxide were found, along with low oxygen concentrations, in the root zones of most of these dead peach trees. The greatest distance of these dead peach trees from the landfill was 70 feet.

In March 1974, landfill gases were found more than 80 feet from the landfill. By then about 70 peach trees ha died. The peach farmer brought th operator of the landfill (the Borough o Glassboro) into the Chancery Divisio of the Superior Court of New Jersey and after a week of testimony the cas was settled out of court to the plaintiff' satisfaction.

The landfill and peach orchard wer examined again in the early summer c 1975. The landfilling was complete an appeared to have an adequate cover c soil material. Some minor settlemer had taken place, causing surface wate puddles to form. More than half of th mature peach trees adjacent to the lanc fill in 1971 had been removed as part c the farming procedure and were r placed in 1973-74 with new trees. How ever, the young trees in the row neares the landfill died and were replaced wit new trees. These too died, in the sprin of 1975.

No corrective measures have bee taken to reduce the lateral movement

Figure 1.—Commercial peach orchard adjacent to completed refuse landfill in Glassboro, N. J. Dead peach trees can be seen in the rows nearest the landfill in foreground.



these gases. We expect that the farmer will continue to lose peach trees planted near the landfill.

Cherry Hill, Camden County

This 9- to 10-acre landfill is surrounded by 28 single-family homes that were constructed before landfill operations began. Refuse 10 to 60 feet deep has been deposited in this former sand and gravel pit. When dumping began in the fall of 1963, only bulky wastes and demolition materials were being deposited. However, the nature of the materials being deposited gradually changed later to include general municipal refuse and garbage. Dumping was completed in 1970, and Cherry Hill Township has since been making efforts to turn this former landfill into a municipal park. The fill had been placed in a manner to incorporate esthetically pleasing hills and slopes within the park perimeter; topsoil has been brought in, and the area has been seeded.

We were first called to this area by the Rutgers Camden County Agricultural Agent in January 1969 to help determine the cause of vegetation death in the backyard of a home abutting the landfill. A spruce tree, rhododendron, Japanese yew, azaleas, dogwood trees, flowering peach trees, Scotch broom, arborvitae, Douglas-fir, and an area of lawn grass had recently died. Our soil gas tests indicated the presence of combustible gases, carbon dioxide, putrid ground odors, and the lack of oxygen.

Periodic checks made in this area revealed that vegetation injury and deaths seemed to be progressing gradually from the landfill toward the houses. In June 1971 a general inspection of the entire area indicated that there were clumps of dead vegetation at various points around the entire periphery of the landfill. At this time it was recommended that the responsible government officials check the complete landfill to see if gases might be migrating from the landfill into backyards and toward other homes.

Between December 1971 and January 1973, four different 10- to 15-foot deep stone trenches were installed in an effort to prevent the lateral movement of gases from the landfill to the adjacent properties. Only some of these trenches were successful in stopping this. In April 1974 the legal case between a dozen residents and Cherry Hill Township, the owner and operator of the landfill, was heard in the Chancery Division of the Superior Court of New Jersey. After a week of testimony the case was settled out of court. The plaintiffs received $60,000 in settlement. In addition, the township was required to vent the landfill gases from the periphery of the landfill.

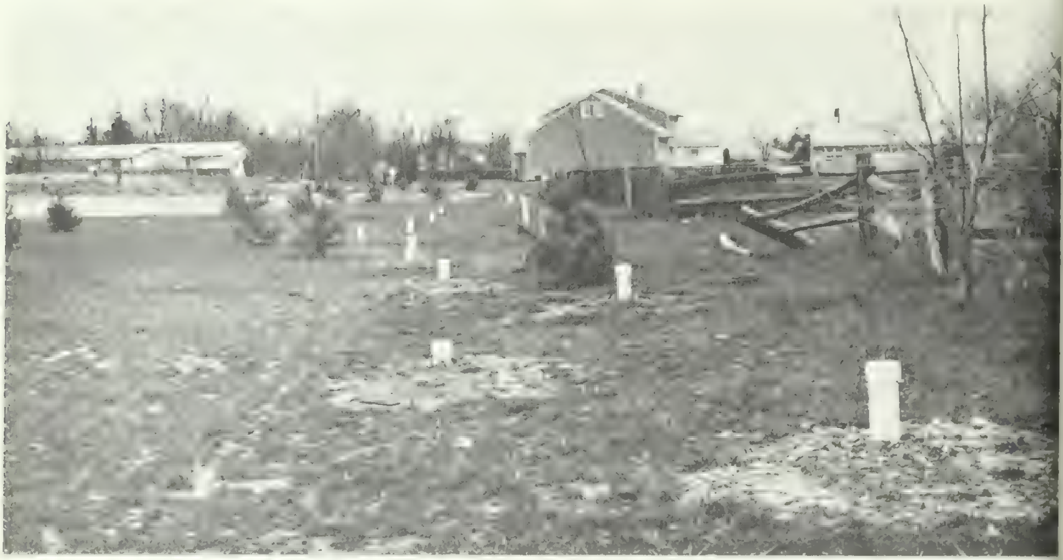
In the fall of 1974 vertical venting pipes were installed on the periphery of the landfill (fig. 2). Many of the vent pipes along the eastern periphery of the landfill have been vandalized and the tops broken by rocks. However, it did not appear that the vandalism decreased the efficiency of these plastic pipes for gas venting.

In April 1974 a single maple tree was planted in the lower elevations of this landfill park. No sign of this maple tree could be found in March 1975. It had disappeared. Only one clump of naturally seeded trees was noted in the spring of 1974. This was a group of maple trees that have been growing for a number of years near the southeastern corner of the landfill. Tests indicated that gases of anaerobic decomposition were not present in the root zone of these trees.

Examination of the landfill park in spring 1975 revealed that a large number of deciduous and evergreen trees had been planted over much of the park area the previous fall. Species included sweet gum, red oak, crab apple, Japanese poplar, white pine, Scotch pine, and fir. No trees were planted on the tops of the high refuse hills.

As of March 1975 many of the evergreen trees looked brown. There were

Figure 2.—Vertical gas venting pipes in place along the periphery of the landfill in Cherry Hill, N. J. Newly planted trees for landscaping are also shown.



also signs of vandalism: some trees had been pulled from the ground; others had limbs broken off; and some had apparently been stolen. The holes left after the trees had been pulled or dug from the ground appeared to be rather shallow, and the soil beneath them appeared to be very well sealed since water puddles remained in them some days after a heavy rain. Examination of these trees indicated that many of the dead trees did not live because of poor planting practice. Only a limited number of the trees revealed the presence of the combustible gases in their root zone.

During the last half dozen years the vegetation in the backyard of the home has continued to die until only that vegetation near the home remains. It will be interesting to see if the gas vents prevent further gas intrusion into these adjacent lands and permit vegetation growth again. We plan to periodically monitor these plantings to see if the landfill gases present any future problems. Perhaps the vertical vents will alleviate the problem at this location.

Cinnaminson in Burlington County

A landfill in which refuse has been placed to depths of 80 feet on about 100 acres is operating on the northern side of Union Landing Road. A 600-foot-long road interface exists between the landfill and the farm on the southerly side of Union Landing Road. The distance between the edge of the farm and the edge of the landfill is 50 to 60 feet. This space is occupied by Union Landing Road and its right of way. Apparently all sorts of refuse materials have been accepted by the landfill, which began operation about 1965.

In the summer of 1970 the farmer experienced difficulty in growing tomatoes in fields nearest the landfill. Very unpleasant odors, arising from the area of his field nearest Union Landing Road, were noted by the farmer during the spring plowing of 1971. At that time we examined this field for possible problems associated with the landfill. In the fall of 1971 decomposition gases were discovered 300 feet from the landfill. Since the spring of 1971 the farmer has not cultivated the 2 to 3 acres of his fields nearest Union Landing Road. The death of vegetation in the field resulted in erosion of the surface of the field, and a weed cover crop developed.

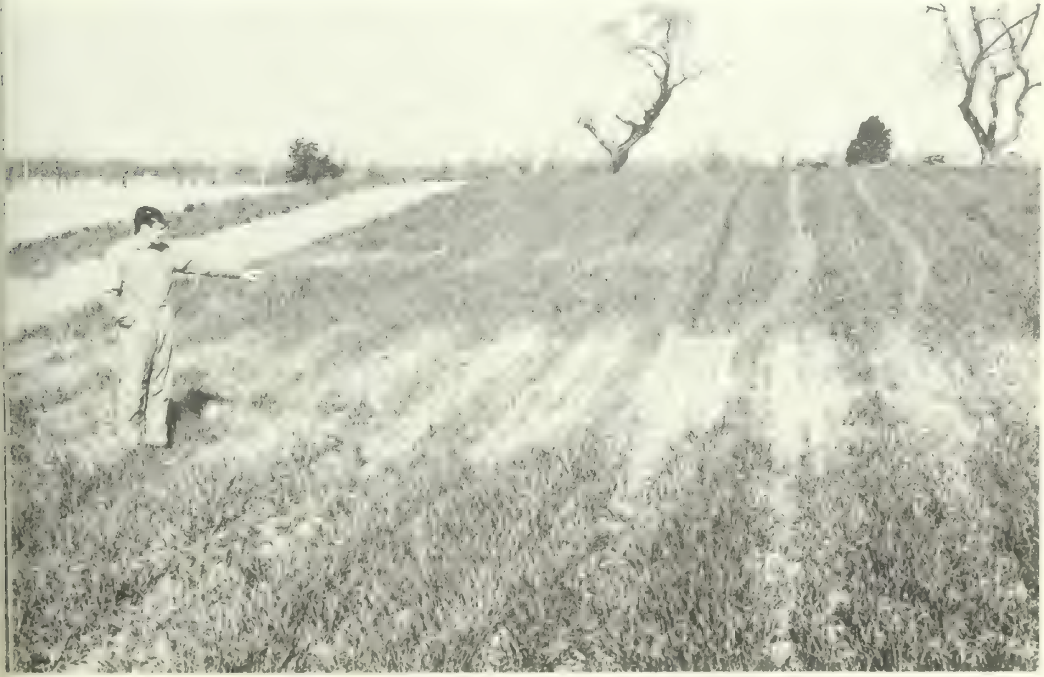
By the fall of 1971, the landfill operator had recognized that his landfill was the source of the farmer's problem. He then installed a 600-foot-long, 10-foot-deep, 3-foot-wide gravel-filled trench the total length of the interface between the landfill and the farm. This did not seem to alleviate the problem. Apparently the gases continued to flow from the landfill beneath the trench into the farm field.

In the spring of 1972 soil tests were made in the areas of the farm where vegetation was undamaged and where the vegetation had been killed by the landfill gases. The nutrient quality of both soil areas was found to be the same.

n March 1973 the landfill operator installed 4-inch plastic vertical venting pipes along the total length of the landfill-farm field interface. These pipes were put in to a depth of 30 to 40 feet on 20-to 25-foot centers.

In April 1973 the farmer and the landfill operator developed an interim agreement relative to payments for damages claimed by the farmer and corrective actions to be taken by the landfill to alleviate the gas problem. In December 1974 the farmer noted areas farther from the field where his rye cover crop was dying (fig. 3). A check of the ground gases in these areas revealed the presence of combustible gases up to 600 feet from the nearest edge of the landfill. In summer of 1975, combustible gases were found more than 750 feet from the nearest edge of the landfill. At this time they were damaging commercial corn and sweet potato crops. It appears that the venting pipes were not functioning properly; although visual examination indicated that ground gases are being vented to the atmosphere by the pipes. Suggestions made

Figure 3.—Rye planting in farm field adversely affected by landfill gases 600 feet from nearest edge of the landfill at Cinnaminson, N. J.



to improve gas-venting include installing pumps on the pipes to withdraw the combustible gases from the landfill and venting from greater depths.

As indicated above, we found landfill gases 180 feet from the landfill in the spring of 1971, 300 feet from the landfill in the fall of 1971, 600 feet from the landfill in December 1974, and 750 feet this summer (1975). However, the migration of these gases has not been constant. Measurements taken at a number of other times indicated that the gases had apparently retreated toward the landfill. Their outward movement seems to be at an uneven rate, depending upon various factors, many of which are not understood. Incidentally, the consultant hired by the landfill company reported that the degree of migrating gases has decreased with time. Obviously our data conflicts with his. Some of this disagreement might be due to making measurements at different locations and times.

We will continue to follow this situation and determine the ultimate fate of the landfill gases and vegetation growth in the fields. Eight to 10 acres of the farm field are now involved in problems of poor or no vegetation due to the adverse influence of gases from the landfill located to the north of the field.

The landfilling directly north of Union Landing Road is nearly complete. Completion of the landfill will involve filling the westerly corner of this former sand and gravel pit. This additional filling will bring the refuse in contact with the soil along Union Landing Road for an additional few hundred feet immediately opposite the Hunter Farm. This includes an area on which a farmhouse is located plus an additional few hundred feet immediately opposite the Hunter Farm commercial farm fields. It is possible that the refuse will be located against a soil bank within about 100 feet of the farmhouse.

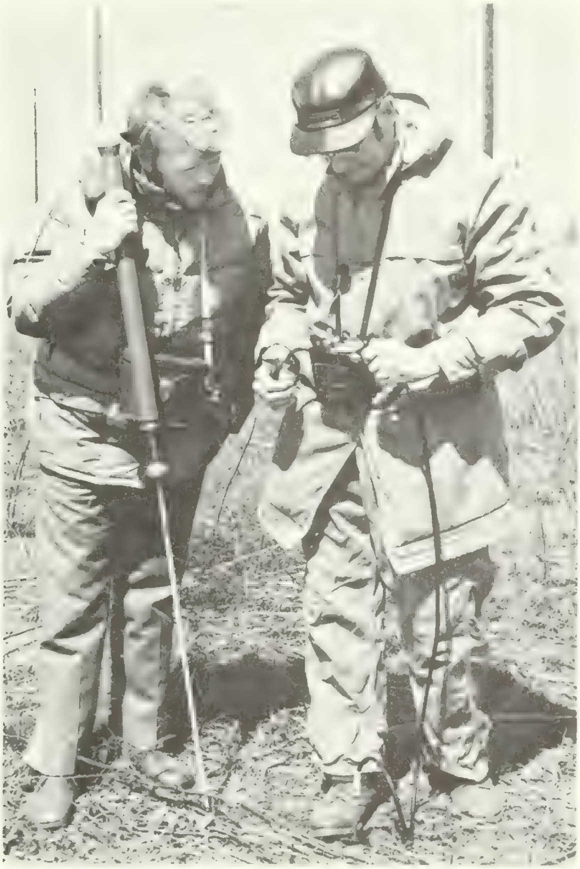
This farmhouse has a dirt-floor cellar, which is used to store various farm crops during the winter. Therefore we have set up permanent gas-sampling stations opposite the landfill area still to be filled. In addition to exposing this farmhouse to possible infiltration of landfill gases, another private home and at least one light-industry building will also be within a couple of hundred feet of the refuse upon completion of the landfill. Unless adequate protective measures, such as a gas barrier or adequate vents or both, are taken to prevent the movement of landfill gases, it is possible that these buildings and additional farm fields will in time become involved with the combustible gases travelling underground from the landfill.

GAS MEASUREMENTS

All our underground gas measurements were made by adapting various gas-measuring equipment that was originally designed for making safety checks and measuring combustion efficiencies. To determine whether or not foreign gases are present in the soil atmospheres, it is necessary in most cases to first make a hole in the ground. Currently we are using a commercial bar hole maker to obtain a 3-foot deep, ½-inch hole. This commercial instrument (fig. 4) incorporates a steel hole-making rod and driving weight in one convenient unit. This same type of unit is used by most gas utility companies when searching for leaks from their underground pipelines. The handle of our hole maker is electrically insulated to prevent a shock should it come in contact with a live underground electric wire.

The sample is withdrawn from the bar hole by use of a 3-foot long nonsparking probe. If desired, a nonconducting probe may be used. A rubber stopper is placed over the upper end of the sampling probe to help seal the bar hole from the ambient air. However, the nature of the sampling method frequently allows large quantities of ambient air to dilute the sample.

Figure 4.—Bar hole maker is held by man on left. Right, reading an MSA Explosimeter to measure the concentration of combustible gases in a sample drawn from the bar hole.



The most convenient test for checking for the gases of anaerobic decomposition of organic matter is with a combustible gas meter. We pass our gas sample, which is drawn from the bar hole, through an M.S.A. Explosimeter, an instrument used by the gas utility companies when checking for leaks in their underground lines. The Wheatstone bridge principle is used in the instrument for determining gas concentration. The combustible gases are burned on a heated catalytic filament, thereby changing its resistance. This unbalances the bridge, giving a reading on the galvanometer.

These combustible gas-measuring instrument readings indicate the percentage of the lower explosive limit of the gases for which the instrument is calibrated. The lower explosive limit for methane is a 5-percent dilution in air. However, it is possible to tell from the response of the meter whether or not the combustible gas concentration is between the lower and upper explosive limits or above the upper explosive limit (15 percent methane in air). By use of a dilution tube on the intake side of the meter, it is possible to theoretically determine the actual combustible gas concentrations up to 100 percent methane. It is also possible to separate heavy petroleum vapors from the lighter hydrocarbon gases by use of an activated charcoal filter on the sampling line. Regular calibration is required.

The carbon dioxide and oxygen concentrations of the ground gases obtained from the bar holes are analyzed by the Orsat method, normally used to measure the efficiency of fossil-fuel-fired furnaces. In our field-test work we use the Bacharach Fyrite carbon dioxide and oxygen indicators. In the carbon dioxide indicator, the CO_2 is absorbed in a potassium hydroxide solution. In the oxygen indicator, a chromous chloride solution is used. Carbon dioxide indicators are available for reading 0 to 20 percent and the 0 to 60 percent concentrations. The oxygen indicators are for determining 0 to 21 percent concentrations.

Unpleasant ground gas odors are frequently an indication of gases of anaerobic decomposition of organic matter. These unpleasant odors can often be checked for by withdrawing a soil sample from the ground and smelling the sample.

We have occasionally used industrial hygiene dry-tube indicators to check for the possible presence of sulfur gases and carbon monoxide. However, in general we find the field test for combustible gases to be the easiest, quickest, and simplest to make. Our next most frequently used field check is for carbon dioxide. Normally we would not expect to record the presence of combustible gases or carbon dioxide with these field-test meters if there were not significant quantities of the gaseous products of anaerobic decomposition present in the soil gases.

Characterization of Biological Particulate Loads in Metropolitan Air

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ABSTRACT.—The atmospheric particulate load includes a wide range of naturally occurring particles of biological origin that serve as a reservoir of allergenic agents in respiratory disease. Improved knowledge of potential aeroallergens is needed by medical clinicians. Aims are to better characterize air spora, qualitatively and quantitatively, and determine daily (by hour) periodicities of occurrence and prevalence of different kinds of spores, and seasonal variations. Main emphasis is on fungus spores about which least is known though they occur in considerable numbers. Efficient volumetric samplers provide time-related deposits of air spora at three sites in Pennsylvania.

INCLUDED IN THE ATMOSPHERIC load of particulates is a wide range of naturally occurring particles of biological origin, such as microorganisms, pollens and other plant spores, fragments of plants and insect parts, etc. This diverse air spora of natural origin also serves as a reservoir of allergenic agents in respiratory disease. Improved knowledge of potential aeroallergens is much needed by medical clinicians.

Characterization of airborne biological particulates is the first phase of a study of aeroallergens being carried out at the Center for Air Environment Studies at The Pennsylvania State University. Aeroallergens are defined as substances encountered in the air which can incite allergic responses. Generally, these are inhalant allergens, and the major responses are allergic rhinitis, including seasonal hay fever, and bronchial asthma.

Primary aims of this phase of the project are to apply modern techniques of air spora study to: (1) characterize qualitatively the potential aeroallergens, mainly fungus spores and pollens, of major regions of Pennsylvania; (2) to provide quantitative volumetric data on air spora; and (3) to determine circadian (daily, time-related) and seasonal periodicity of occurrence and prevalence of different kinds of spores. We also are beginning to relate spore data to appropriate meteorological variables where possible.

The economic impact of aeroallergens can be assessed in only general terms. Of the United States population, about 15 percent may be sensitized easily to many allergenic materials and another 25-30 percent are considered somewhat sensitive *(Kern 1962)*. Approximately 15 million persons in the U.S. suffer effects of hay fever and/or asthma. More than $70 million are spent on prescription medications related to allergic response each year. About 25 million work days are lost per year due to hay fever. Further, lowered work efficiency due to symptoms and sedative effects of some medications is probable. Allergic rhinitis also often increases susceptibility to infections of the respiratory tract. Asthma incidence leads to an estimated $260 million a year in resource costs, including premature deaths, medical treatments and absenteeism *(Finkelstein 1969)*.

Almost any organic material, from plant or animal sources, may be a potential allergen. Among the more common known aeroallergens are pollens, fungus spores, danders (animal hairs, feathers, flakes of epidermis, etc.); house dust (heterogenous mixture); insect parts; algae; certain cosmetics; and products containing linseed oil, organic solvents, etc.

The two most important groups of naturally occurring aeroallergens are the pollens and fungus spores. Pollens are usually considered to cause the most problems, and ragweed is believed to account for some 90 percent of pollenosis in the U.S. *(Hewson 1967)*.

POLLENS IN THE ATMOSPHERE

Pollens are produced in great numbers throughout the world. Of the approximately 100,000 known species of flowering plants, about 10 percent are adapted to wind pollination *(Gregory 1973)*. Most pollen grains range in size from 15 to 50 μm, and most species have distinctive features and characteristic size. Gravitational fall rates range from about 1 to 10 cm/sec. In general in the temperature zone, the tree-pollen season is in the spring, the grass season from late spring through summer, and the weed season mostly in late summer and fall. There are of course variations and overlappings depending on species and climate as well as more local meteorological conditions.

The members of the ragweed group *(Ambrosia sp.)* are prolific pollen producers, and the pollen grains are exceptionally well suited to aerial dissemination. The plants may grow in abundance where soil and cover vegetation have been disturbed as in housing developments, along highways, railroads, etc., as well as on agricultural land.

Millions of acres in the U.S. are infested by ragweeds to some extent. Surveys have revealed as many as 170,000 plants/acre (about 42/m^2) in some fields when no cover crops were grown after winter cereal grains were harvested. About 56,000 plants/acre (11/m^2) were found in a subdivision area under construction *(Hewson 1967)*. An estimated 50 pounds (22 kg) of pollen could be produced by an acre of giant ragweed plants in a season *(Finkelstein 1969)*; at 200 million grains/gram of pollen, this means 4.5 x 10^{12} pollen grains could be produced per acre over an 8-week pollen production period. About 5 to 10 percent of the pollen can be expected to become airborne.

The distance traveled depends on many factors, and it should be noted that airborne particles are being deposited continuously on surfaces near the ground. Despite deposition, the proportion escaping to be transported some distance from the source places considerable numbers in the air to be dispersed over large areas. Concentrations of several hundred ragweed pollen grains/m^3 of air are not uncommon over much of the central and eastern U.S. during the ragweed season each year *(Hewson 1967)*. Peak concentrations over cities some distance from major sources may reach several hundred per m^3 in some areas. Cities often have local sources of ragweed as well.

The relationship of concentration of pollen in the air to production of symptoms is not well known. Individuals may differ greatly in their sensitivity to dosage. However, it has been reported that as few as 100 pollen grains inhaled over a 1-hour period often caused symptoms, and in one individual as few as 30 incited hay fever *(Connell 1968)*. Since the volume of air inhaled approximates 1 m^3/hr for an adult engaged in light activity, it is apparent that exposure levels commonly encountered could readily incite allergic responses in susceptible individuals. It is also known that being sensitized to one pollen or substance can increase sensitivity to certain other allergens *(Connell 1969)*.

Ragweed pollen fall rate in air due to gravity is about 1cm/sec, thus convection currents can readily carry them aloft. Most ragweed pollen is released in the morning hours, but concentration peaks may occur also later in the day or at night due to pollen descending from high altitudes. In general there is a decrease in concentration with height, though greater numbers may occur at 1 or 2 km altitude than at ground level, due to various atmospheric factors and source locations *(Gregory 1973)*.

FUNGI IN THE ATMOSPHERE

Fungus spores, which are usually more prevalent in air than pollens (often >75 to 1) also can act as potent allergens *(Hamilton 1959)*. Fungi grow on organic matter and some parasitize living plants, insects, and animals. Most spores occurring commonly in outside air originate from fungi growing on plant debris or on surfaces of living plants, trees, etc., rather than from soil as sometimes inferred. Air in buildings may in addition to spores from outside air also contain spores from moldy surfaces and mildewed materials within the building.

Fungus spores are usually smaller than pollens. Most range in size from 3 to 30 μm (the size range of water droplets in clouds). Gravitational settling rates are 0.05-2 cm/sec, and thus most fungus spores become airborne and remain suspended longer than pollens. Viable fungi have been recovered at altitudes of 17 miles (27 km), and over oceans thousands of miles from land as well as over the North Pole *(Ingold 1971)*.

Many thousands of species of fungi produce spores that may become airborne. (Fortunately only a few hundred types are found in air samples that we have studied!) A few examples of prolific spore production are as follows: a single large puffball may contain 7 x 10^{12} spores; a large specimen of bracket fungus may produce 3 x 10^{10} spores/day for a 5-month season; an average field mushroom might produce 10^8 spores per day; a single smut-diseased wheat grain may contain 12 x 10^6 spores; and a single colony of blue mold *(Penicillium* sp.*)* 2.5 cm (1 in) diameter may bear about 4 x 10^8 spores *(Ingold 1971)*.

Concentrations of about 10,000 fungus spores/m^3 of air may be typical on a summer afternoon *(Hirst and Hurst 1967)*. Numbers may vary greatly, depending on species prevalent, previous conditions for growth and spore production, location, climate, geography, season, weather (temperature, humidity, wind speed, turbulence, etc.), time of day, biotic factors, etc. Exposure depends on an individual's activity and location at any particular time.

Spores of the genus *Cladosporium (Hormodendrum)* seem to be the most numerous found in samples from several places in the world, often comprising about 50 percent of the total spores recorded. This genus is also considered one of the more allergenic encountered.

SAMPLING SYSTEMS

The practice of allergic medicine in the United States has, to some extent, been dependent upon an incomplete knowledge of the kinds and amounts of spores in the atmosphere, particularly fungal spores. This project aims at providing improved characterization, qualitative and quantitative, of air spora occurrence. The main emphasis is on fungus spores, since pollens are better known *(Wodehouse 1971, Jones 1952, Hyde 1959, Hyde and Adams 1958)*, and the modern techniques of air-spora study employed are well suited to improved sampling of the smaller fungus spores. Also, excellent studies of ragweed pollen production and dispersal have been undertaken *(Sheldon and Hewson 1962, Ogdon et al. 1966 and 1969, Harrington 1965, Raynor et al. 1973 and 1974)*.

In 1946, the American Academy of Allergy standardized the methods of assessing pollen in the air *(Durham 1946, Durham et al. 1947)*. This "gravity settling" method was extended to estimates of fungus spores in 1948 *(Merksamer and Sherman 1958)*. In prior surveys, culture-plate studies were made. Much useful information has been derived from these methods, and they are still in common use.

After the development and testing of efficient volumetric suction samplers *(May 1945, Hirst 1952, Andersen 1958)* it became quite clear that the simple gravity samplers can give very distorted estimates of pollen and fungus spore concentrations and may result in serious underestimation of the number of different types actually present in the air. Problems are more serious for fungus spores than for most pollens, and this is particularly true for species producing smaller spores *(Gregory 1952, Gregory and Hirst 1957, Ogden and Raynor 1960, Solomon 1970, Ingold 1971)*.

In the last 20 years a great deal has been learned about circadian and seasonal periodicities of several fungus spores and pollens, especially in England, and in some studies in the U.S. The techniques of volumetric sampling, coupled with time discrimination of deposits, showed clearly that a considerable variation often occurs from hour to hour, between night and day, as well as seasonally *(Hirst 1953; Pady et al. 1962, 1967, 1969; Gregory 1952* and *1973; Ingold 1971; Haard and Kramer 1970)*.

RATIONALE

There is little definitive quantitative information concerning fungal aeroallergens for most of North America and essentially none for Pennsylvania. It is to be expected that several other fungi will be shown to be quite prevalent in most areas when systematic volumetric sampling is done *(Gregory and Hirst 1957, Hamilton 1959, Adams 1964, Sayer et al. 1969)*. Further, we do not have qualitative or quantitative comparisons of fungal air spora for different regions as affected by climate, seasons, vegetation sources, etc.

A result of the general state of knowledge is that allergists are in a poor position to relate observed symptoms to known botanical events, and must rely mostly on sensitivity testing with prepared extracts of a limited number of empirically determined allergenic materials. Improved methods of characterizing the air spora will reveal more organisms that should be tested as potential allergens, and may elucidate the causes of some of the seasonal and perennial allergies whose etiologies are still unknown *(Greenburg et al. 1966, Girsh et al. 1967, Paulus and Smith 1967)*.

PROCEDURE

Volumetric samplers are operated at such heights above ground (about 30 m) to determine the general concentrations of air spora. Many if not most of the spores moving over a city have exogenous origins some distance away *(Harrington 1965, Ogden et al. 1966, Freedman 1967, Davies 1969b)*. By situating samplers well above ground level (to avoid obstructions to free air movement, such as nearby buildings, tall trees, etc.), local site effects are minimized. Bias due to very localized sources of spora from within a city is reduced by allowing vertical and horizontal mixing time before reaching the sampler. Thus each sampling station becomes representative of a considerably larger area *(Davies 1969a)*.

The Hirst *(1952)* spore trap is a volumetric suction-impaction sampler that gives continuous and time-related particle deposits from known volumes of air. The Casella model (C. F. Casella & Co., Ltd., London, England) is a 24-hour sampler utilizing a standard microscope slide. The Burkard model (Burkard Manufacturing Co., Ltd., Herts, England) operates continuously for 7 days, using a plastic tape on a revolving drum as the collection surface. Both models draw air at 10 liters/

minute through a 2x14-mm orifice. Particles impact on the silicone-greased collection surface, which moves continuously at 2 mm/hr.

Counts and identification are made by microscope at about 1,000 magnifications at positions corresponding to 2-hour intervals. Data derived show the kinds and number of air spora present (per m^3 of air) and the times of occurrence throughout each day.

Weather data are being obtained from stations near the sampling sites for correlation with air spora data. Meteorological information includes temperature, precipitation, wind speed and direction, and relative humidity. Information on large-scale weather systems or other meteorological data available may also be useful in characterizing patterns of occurrence of air spora as related to changing environmental conditions.

The three sampling stations, started in mid-1972 and currently operating are at: (1) Pittsburgh, atop the 11-story Veterans Administration Hospital in Oakland; (2) Philadelphia, on the roof of a 12-story building in Jenkintown; and (3) State College, at the Pennsylvania State University campus on the top of the press box at the football stadium. They are located to provide data representative of three different regions and climatological zones *(Dailey 1971, Dethier and Vittum 1963)* and should provide information typical of large portions of the state, as well as comparisons of two urban settings and a rural setting. Additional sites may be sampled in the future for more direct comparisons of air spora and clinical observations in close cooperation with allerists.

SIGNIFICANCE

Improved knowledge of air spora is needed by medical clinicians. Prospects are good for correlating clinical observations with types, concentrations, and variations in air spora. A better understanding of what is in the air, and when, will give allergists important leads for selecting allergenic materials and extracts for testing and treatment. Fungal spores are ubiquitous and the most common biological component of the atmosphere in most areas. Their importance may well be underestimated in general, particularly those that occur in great numbers but have seldom been revealed by methods commonly in use. Knowledge of circadian periodicities of air spora can be important in determining times of day and peak concentrations of aeroallergens to which patients may be exposed. It seems likely that large populations can be included within the zones applicable to the selected sampling sites and representative of the areas, particularly the regions surrounding the large urban centers.

RESULTS

A great number of different kinds of spores are observed in most samples. Many can be identified readily, and separate counts are made of several generally considered allergenic, such as *Cladosporium, Alternaria, Helminthosporium,* and *Epicoccum.* Special note is made of others when they occur in relatively greater numbers than usual.

Counts are routinely made by using a microscope at about 1,000 magnification to ensure seeing the smallest spores, which can be missed at lower powers. This high magnification, though more time-consuming, allows less chance of misidentifications, especially of the smaller and colorless types, which often are seen in great numbers. To set some reasonable limit on the time involved in reading samples, other spores are placed in categories as to type and appearance. These groups are basidiospores, either colored or hyaline, ascospores (two or three types), Penicillium-Aspergillus types, etc. Separate counts are kept of ragweed pollens, which occur for approximately 2 months in the fall, and a total count for other pollens. Total insect parts and other plant parts are also routinely counted. Special notice is made of unusual occurrences of types not usually seen, or normally of low frequency, for possible correlations with clinical data at a later time. The sample slides are essentially permanent and can be reexamined when desired for more detailed or special studies.

Cladosporium

The most consistent and generally numerous type of fungus spores found are of the genus *Cladosporium.* This fungus, in the medical literature often referred to as *Hormodendrum*, has long been recognized as allergenic. The spores are usually released during drying conditions, that is, during the period of lowering relative humidity and increasing air turbulence such as found in the mornings of sunny days. High counts of this group may also occur at other times, even at night, as a result of gravitational settling or the subsidence of air from higher altitudes containing heavy spore loads derived from air that rose earlier in the day, or even on previous days, many miles upwind. Figure 1 illustrates typical occurrences of *Cladosporium* to be expected.

Basidiospores

Most of these spores come from the more commonly seen fungi, due to their larger size, such as mushrooms, bracket fungi, and puffballs. Some basidiospores are released throughout the day as long as sufficient moisture is available to the fruiting structures. Others apparently are released mainly at night when humidity is usually the highest. As a result, peaks of basidiospores in the atmosphere are usually observed between midnight and 0600 hours. It should be noted that because of their small size (mostly 10 μm or less), basidiospores have not often been seen or counted by using the old standard gravity slide techniques. Only with volumetric sampling are we able to provide data as shown in figure 1. The common occurrence of basidiospores in considerable numbers, at times the most prevalent spore group in the atmosphere, has not been generally known to allergists. A need for more clinical testing for sensitivity to members of this group of fungi seems warranted.

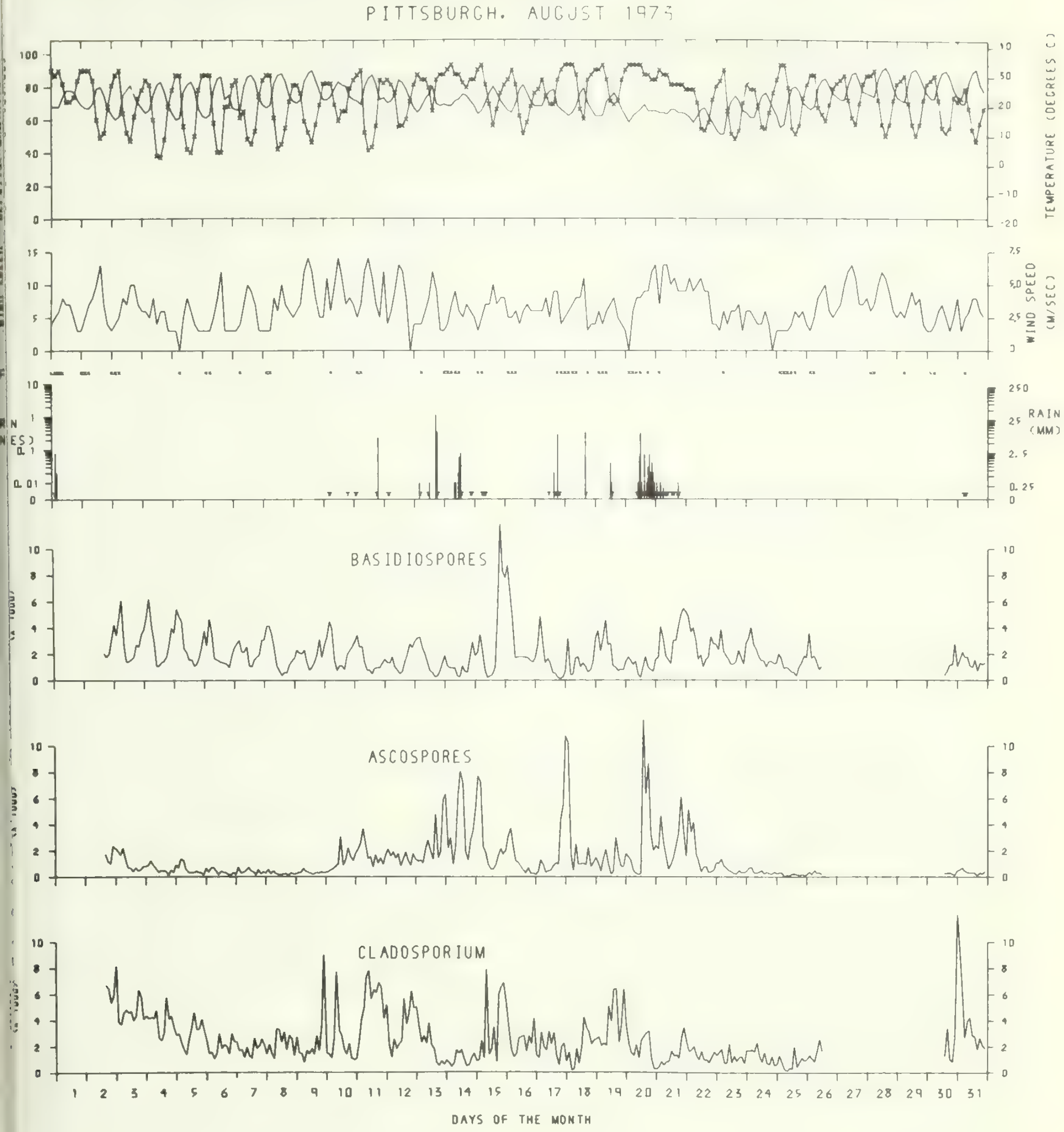
Ascospores

These are the spores from another major group of the fungi, the Ascomycetes. Characteristically, spore release in this large group is dependent upon moisture, and therefore counts are usually highest at night. Following periods of dry weather there may be tremendous increases in spore release shortly after rain. This is well illustrated by our data for 10 and 11 August (fig. 1), where immediately after very small amounts of rain as recorded by the Pittsburgh weather station, the number of ascospores collected increased immensely. Ascospores are considerably smaller than most pollens and often have not been found in such numbers in earlier studies. Because of the high numbers of ascospores sometimes encountered, it seems likely that allergies may be incited by at least some of these. It may be that certain cases of known sensitivity to other spore types, such as *Phoma or Fusarium*, may also be incited by the ascospore stages of these fungi that may more readily enter the atmosphere in outdoor air.

Other Fungi

Many other fungi occur regularly, or occasionally, in variable numbers. Some that have long been known as allergens, such as *Alternaria* and *Helminthosporium* types, occur fairly regularly but in much lower concentrations compared to the above-mentioned types. This does not necessarily mean they are less important than assumed as aeroallergens, since they may have potent antigens and thus require few spores to produce allergies. It does, however, seem to em-

Figure 1.—Fungus spore concentrations at 2-hour intervals, from Pittsburgh air samples, August 1973.



phasize the potential importance of spore types usually occurring in much greater numbers but which have not been known or tested clinically.

Miscellaneous Biological Particulates

Several other biological particles are seen in samples, usually in relatively low numbers, such as insect scales, algae, plant hairs, lichen fragments, and moss and fern spores. Their importance as potential aeroallergens has not been fully assessed.

Pollens

Even though the data presented were collected during the usual ragweed season, the numbers of pollens were low compared to the fungus spores present. During August (fig. 1) the daily average concentration of ragweed pollen was 53/m^3, ranging from 2/m^3 on 3 August to 250/m^3 on 30 August; and in general increasing throughout the month. Average concentrations for the first half of the month were 22/m^3, and for the second half, 85/m^3. Peak hourly concentrations ranged from about 25/m^3, occurring on 3 to 7 August, to about 600/m^3 at 1100 hours on 31 August. That was also the peak recorded for the season in Pittsburgh, although ragweed pollens persisted in low numbers well into October.

Few other pollens were seen during August. One type, probably from the nettle plant, reached about 200/m^3 on 11 August. This type is small for pollen (15 μm) and has probably been underestimated on gravity samplers. It has been reported as allergenic.

General

As would be expected, the air spora are most prevalent during the warmer months. Fewer occur in winter, but concentrations of several hundred fungus spores per m^3 of air are not uncommon.

It is clear from the data thus far studied that there occurs a tremendous variation in types and numbers of pollens and fungus spores in the atmosphere, from day to day and hour to hour, as well as seasonally at all sites sampled. The circadian periodicities are evident (fig. 1) as the cyclic variations that occur approximately every 24 hours much of the time.

DISCUSSION

Most previous studies of aeroallergens have depended upon sampling methods, the result of which correlate very imperfectly with the true spore content of the atmosphere, both qualitatively and quantitatively. More reliable assessments are needed. In addition, most previous methods could not provide data on variations in air spora occurring throughout a 24-hour period. Such information could have an important impact on determination and control of allergic diseases.

Improved characterization of the biological particulates in the atmosphere should be of considerable use to allergists. Prospects are good for correlating clinical observations with types, concentrations, and variations of air spora. It is expected that new associations will be evident in the etiology of asthmas and epidemiology of seasonal allergic rhinitis when certain spores are found in previously unrealized high concentrations. Knowledge of circadian periodicities can be important in determining times of day and peak concentrations of aeroallergens to which patients might be exposed. Data accumulated will also be tested for possible correlations with climatic and meteorological parameters. These and other studies in cooperation with allergists will constitute the second phase of this study of aeroallergens and their impact on the susceptible population.

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Retention of Particulate Lead on Foliage and Twigs of a White Pine Windbreak

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ABSTRACT.—The removal of particulate lead from the air by a roadside windbreak of white pine containing 8 rows of 25-year-old trees and 27 m in depth was studied. Knowledge of particulate trapping and retention was gained by atomic absorption spectrophotometry of the lead burden of foliage and twigs of various ages adjacent to and far from the road. The effectiveness of the windbreak was also shown by comparison of the lead content of the soil beneath the windbreak with that of an adjacent open, undisturbed field.

VEGETATION AND SOILS adjacent to heavily-traveled roads incur significant deposits of lead from automobile exhaust *(Cannon and Bowles 1962, Motto et al. 1970, Page et al. 1971)*. The lead is associated with chlorine and bromine in particles on or embedded in plant surfaces *(Heichel and Hankin 1972)*. Observations that the lead burden is frequently retained tenaciously by vegetation *(Smith 1972, Heichel and Hankin 1972)* prompted us to speculate that foliage and twigs of roadside coniferous windbreaks might filter particulate lead from the air and reduce its dispersion from the road. The efficacy of a windbreak in removing particulate lead was evaluated by analyses of the lead burden of foliage and twigs of various ages adjacent to and far from the road. Also, we compared the lead content of the soil beneath the windbreak with that of an adjacent open undisturbed field.

MATERIALS AND METHODS

Site

The windbreak of white pine *(Pinus strobus)* trees growing as a dense roadside screen west of the curb of a heavily-traveled two-lane highway in Hamden CT contained 8 rows of 25-year-old trees and was about 12.2 m tall in the center. The near drip-line of the windbreak commenced 3 m from the curb of the highway, and the far drip-line terminated 30.5 m from the curb. Thus the windbreak was about 27 m in depth.

An open field adjacent to the highway and about 150 m north of the windbreak served as a control site for measuring lead accumulation in soil. The field had not been tilled since establishment of the windbreak and supported a lush growth of perennial forage species that was mowed once a year and allowed to decompose.

Table I.—Daily traffic flow past the windbreak in 1973

Month	Average daily traffic[1]
	No. of vehicles
January	12,960
February	12,960
March	13,680
April	14,500
May	15,600
June	15,800
July	15,000
August	14,700
September	14,800
October	15,100
November	14,400
December	13,200

[1]Source: Connecticut Department of Transportation.

Traffic Flow

Commuter and truck traffic passed the windbreak at 65 to 73 km/hr. A survey station maintained by the Connecticut Department of Transportation 1.6 km north of the windbreak recorded the average daily traffic flow on a monthly basis during 1973 (table 1). Traffic volume during the course of the investigation ranged from 15,800 vehicles/day in June to 13,200 vehicles/day in December, with a mean of 14,800 vehicles/day.

Wind and Precipitation

Records of the prevailing wind patterns in the locality of the windbreak *(Brumbach 1965)* revealed that the trees were downwind of traffic for 3 of the 8 months of the investigation—May, September, and October (table 2).

Precipitation for the 30-day period before each sampling was monitored at the Mt. Carmel weather station located 4.8 km south of the windbreak (table 2).

Sampling and Analysis

Branches were sampled on seven occasions from May to December 1973 from limbs 0.75 to 1.5 m above the soil surface, separated into needles and twigs of various ages, oven-dried, and ground. For measurements of soil lead content, transects were established through the windbreak and across the open field. Samples of the upper 5 mm of needles on the soil beneath the windbreak, and of the upper 20 mm of mineral soil under the windbreak and open field, were oven-dried. Lead analyses were by atomic absorption spectrophotometry *(Fletcher 1971)*.

RESULTS AND DISCUSSION

Knowledge of particulate retention was revealed by the lead burden of needles and twigs adjacent to and far from the road. Needles on the windbreak adjacent to the road persisted 27 months between emergence in late May and senescence 2 years later in September, while needles far from the road persisted 1 month longer.

The lead burden of older needles was consistently greater than that of younger needles (fig. 1 and 2). On 14 June, for example, 1972 needles near the road bore nearly 4-fold and 1971 needles nearly 6-fold the 35 μg/g dry-weight lead burden of 1973 needles. The 1972 needles far from the road bore 3-fold and 1971 needles nearly 6-fold the 5 μg/g lead burden of 1973 needles. Except for the 20 August samples obtained near the road, and the 29 December samples far from the road, older twigs bore a greater lead burden than newer, younger twigs (fig. 1). Clearly, the lead burden of coniferous foliage and twigs was directly related to the duration of exposure to contamination.

The lead burden of needles and twigs varied with time of year (fig. 1 and 2). The burden of 1971 needles sampled

Table 2.—Wind and precipitation in the vicinity of the windbreak

Sampling date (1973)	Mean monthly wind direction	30-day cumulative precipitation at sampling
		(cm)
15 May	East	13.31
14 June	Southwest	9.73
July	Southwest	—
20 August	Southwest	11.71
17 September	Northeast	4.60
30 October	Northeast	8.38
26 November	Northwest	7.34
29 December	Northwest	30.33

Figure 1.—Patterns of retention of lead on needles and twigs located on the near side of a white pine windbreak adjacent to a road.

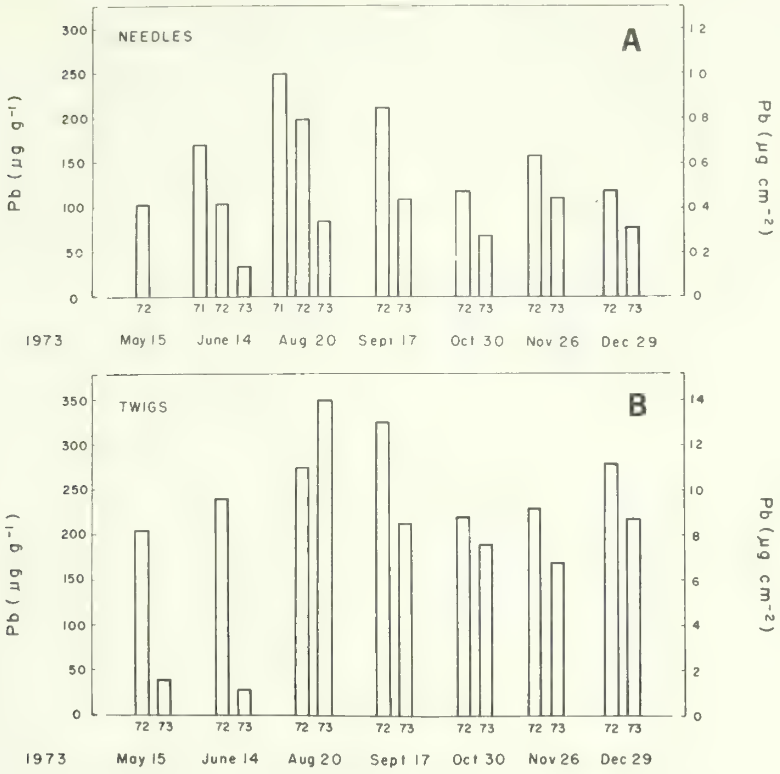
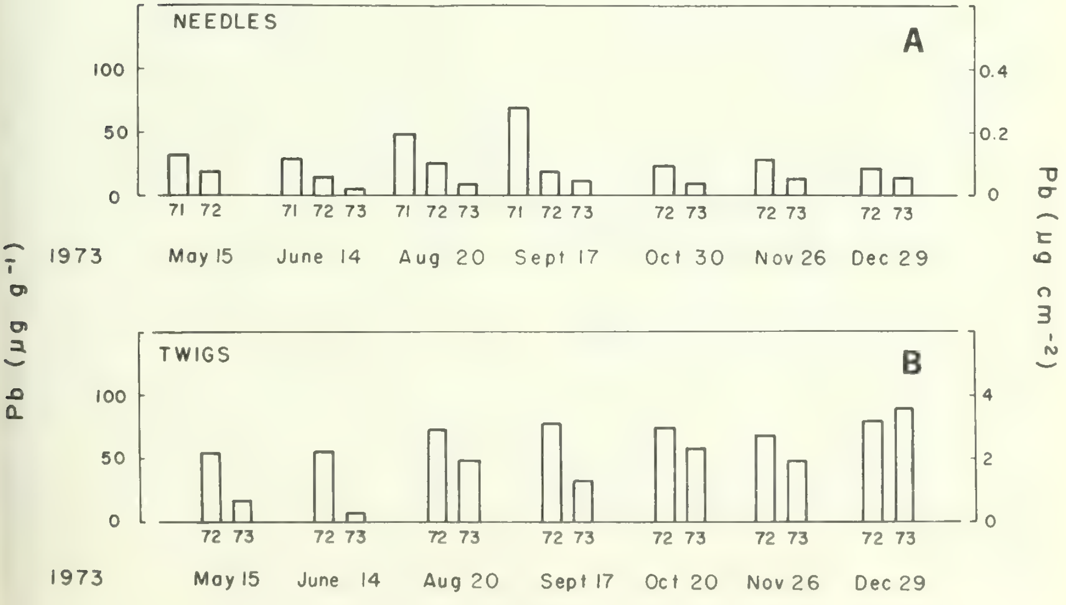


Figure 2.—Patterns of retention of lead on needles and twigs located on the far side of a white pine windbreak adjacent to a road.



near and far from the road increased from May until they were shed in September. The lead content of 1972 and 1973 needles obtained adjacent to the road peaked in September and then declined during the remainder of 1973. In contrast, the lead burden of 1972 and 1973 needles sampled far from the road remained relatively invariant throughout the year (fig. 2A).

The increase in the lead burden of 1972 and 1973 twigs near the road continued until August, commenced to decline about 1 month before that of needles, and then increased slightly in December (fig. 1B). The lead content of 1972 and 1973 twigs far from the road slowly increased throughout the year, in contrast to the pattern of lead accumulation on twigs adjacent to the road (fig. 2B). Adjacent to the road, therefore, the pattern of lead accumulation throughout the year on twigs was similar to that of needles except for a slight shift in phase.

The pattern of lead accumulation on fully expanded needles varied with precipitation in the interval preceding sampling (table 2, fig. 1A). About 4.6 cm of precipitation, 61 percent less than in the previous sampling period, occurred between 20 August and 17 September. Concurrently the lead burden of 1972 foliage increased 2 percent and that of 1973 foliage 29 percent by 17 September compared with 20 August. In contrast, 8.4 cm, or 82 percent more rain fell in the 30 days ending on 30 October, and the lead burden of 1972 and 1973 foliage was diminished about 45 percent compared with that of the 17 September sample. About 7.4 cm of precipitation, or 13 percent less than in the September-October interval, fell in the 30 days ending 26 November. This decrease in precipitation was accompanied by a 32-percent increase in the lead burden of 1972 foliage and 60 percent increase in that of the 1973 foliage on 26 November compared with 30 October.

As a final illustration, 30.3 cm of water fell as rain, sleet, and snow in the 30 days before the 29 December sampling. This abrupt increase in precipitation was accompanied by a decline of 24 percent in the lead burden of 1972 foliage and 30 percent in that of 1973 foliage compared with 26 November. In contrast, the pattern of lead accumulation on twigs was unrelated to the pattern and quantity of precipitation, presumably because particles are less easily dislodged from the rugged topography of twigs than from the waxy, even surfaces of needles.

The seasonality of traffic flow apparently had no effect on the pattern of lead accumulation on foliage and twigs adjacent to the road (table 1, fig. 1A and 2A). Peak traffic flow occurred in May and June, but maximum lead accumulation occurred in September. Traffic flow increased between August and October, but the lead burden of twigs and needles declined. Compared with the changes in lead burden related to precipitation, seasonal traffic-volume changes of 3 to 8 percent were clearly insufficient to be reflected in lead deposition on needles and twigs. Finally, the expected dilution of the lead burden by rapid foliage and twig growth from May through July did not occur. Indeed, lead accumulated rapidly on foliage and twigs at this time of year.

Retention of lead by needles and twigs was evaluated on mass and area bases (fig. 1 and 2). Twigs of various ages near and far from the road retained about 115 percent more lead/g than similarly located needles. We observed, however, that needles displayed about 10-fold more area/g than twigs. Thus, twigs retained about 2,050 percent of the lead burden/cm of similarly located needles. Clearly, the surfaces of twigs retain particles more effectively than the surfaces of needles.

With these retention patterns, the lead burden of a single tree in the windbreak can be illustrated. Unpublished data of our colleague George Stephens reveals that a 12-m-tall white pine growing in a dense planting would have about 15 x 10^4/cm^2 of woody surface and about 15 x 10^5/cm^2 of foliage surface. Although the tree exposed about 10 fold more foliage than woody surface, the woody surfaces retained about 20-fold the lead burden of foliage (fig. 1 and 2). Thus, about two-thirds of the lead on a tree in the windbreak would be retained on the wood, and the remaining third on the needles.

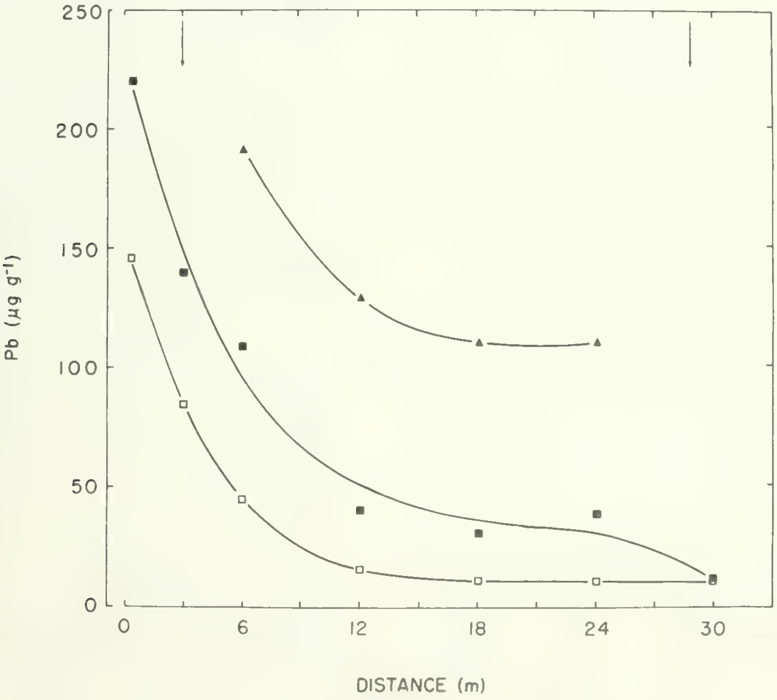
Comparing the soil lead burden beneath the windbreak with that of the open field demonstrated the increased accumulation resulting from the presence of the windbreak (fig. 3).

In the open field, the lead content of the upper 2 cm of soil declined from about 150 μg/g 0.3 m from the curb to 12 μg/g at 18.3 m from the curb, and remained at 12 μg/g to 30.5 m from the curb. However, the soil between the curb and the near drip-line of the windbreak contained 140 to 220 μg/g lead, or about 50 percent more than that of the open field at a similar distance from the road.

Within the windbreak, the soil contained 110 μg/g lead 6 m from the curb to 38 μg/g 24 m from the curb, or about double the lead burden of the field soil at similar distances from the curb. Beyond the far drip-line, the lead burden of the soil near the windbreak, 12 μg/g, was similar to that of the field soil at the same distance from the curb (fig. 3).

Compared with that of the open field, the lead burden of the soil beneath the windbreak might be enhanced by incorporation into soil of needles, twigs, and bark that fall from the trees, by re-

Figure 3.—The lead burden of the needle litter (▲) and soil (■) beneath a windbreak, and of soil in an open field (☐) at various distances from a road. The curves are drawn by hand. Distance=0 is the curb, and the arrows indicate the canopy drip-lines.



moval of impacted lead from the surfaces by precipitation, and by increased sedimentation of particles from the air.

That needlefall would enrich the soil with lead was shown by sampling the litter layer beneath the windbreak. The uppermost 5 mm of needles beneath the windbreak was enriched 76 to 300 percent compared with the upper 2 cm of underlying soil. The lead content of the needle litter on the roadward side of the windbreak was about 190 μg/g, similar to that of the 1971 needles that were sampled prior to senescence in early September. The lead burden of the needle litter mirrored that of the underlying soil and diminished with distance into the windbreak (fig. 3). The rates of deposition of lead from twigs and bark in the litter layer remain to be evaluated.

There have been numerous reports that, in the laboratory, washing with water removes lead from leaf surfaces rather easily *(Page et al. 1971, Smith 1972, Little 1972)*. Our field results further illustrate this by revealing that the lead burden of needles, but not of twigs, varies with patterns of precipitation.

Compared with needles, the invariance of lead removal from twigs by precipitation is probably due to the characteristics of woody surfaces. Lead particulates are undoubtedly less easily eroded from the fissures, cracks, and seams of woody surfaces than from comparatively smooth needle surfaces.

The pattern of wind movement into and through windbreaks might be of substantial significance in the deposition of lead-bearing particulates. For a windbreak having a composition and dimensions similar to ours, Caborn *(1957)* showed that the wind velocity on the leading edge was reduced to about 70 percent of the free wind velocity. That sedimentation of particles from moving aerosols increases with diminishing wind speed is well established *(Davies 1966)*. Moreover, 30 to 50 percent of the particulate lead in automobile exhaust is larger than 5 μm diameter *(Hirshler and Gilbert 1964)*, has settling velocities greater than 0.3 cm/sec, and likely settles more rapidly within the windbreak than without.

Compared with the open field, therefore, reduction of wind velocity at the roadward edge of the windbreak might account for a significant proportion of the increased lead burden in the soil adjacent to the road. Additionally, eddy circulation on the leading edge of a relatively impenetrable windbreak is groundward *(Caborn 1957)*, and this pattern of air movement might enhance deposition of particulates on the soil surface.

Within a windbreak having a structure similar to ours, Caborn *(1957)* observed that the windspeed was only 50 to 60 percent of the free wind velocity. A halving of windspeed might be expected to double the rate of particulate sedimentation from moving aerosols *(Davies 1966)* like automobile exhaust dispersing from roadways. Our observations that the soil within the windbreak bore about double the lead burden of that of the open field therefore conform to expectation.

Windbreaks have long been used to shelter plants from the desiccation of brisk and persistent winds. Our results, however, suggest another role for windbreaks in the urban environment: to act as a sink for particulate pollutants and thereby beneficially modify their dispersion from roadways.

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A Model for Estimating Air-pollutant Uptake by Forests : Calculation of Absorption of Sulfur Dioxide from Dispersed Sources

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ABSTRACT.—The computer model presented in this paper is designed to estimate the uptake of air pollutants by forests. The model utilizes submodels to describe atmospheric diffusion immediately above and within the canopy, and into the sink areas within or on the trees. The program implementing the model is general and can be used with only minor changes for any gaseous pollutant. To illustrate the utility of the model, estimates are made of the sink strength of forests for sulfur dioxide. The results agree with experimentally derived estimates of sulfur dioxide uptake in crops and forest trees.

AS DEFINED BY SMITH *(1972)*, there are three levels of interaction between forests and air pollution. The most obvious and most studied interaction is at high pollution levels where there is visible air-pollution damage or mortality of forest trees. At a lower level of pollution concentration there may be no visible damage, but more subtle damage may occur, such as loss of productivity or changes in species composition. Finally at still lower concentrations there may be no damage or possibly even a beneficial effect on the forest. At this lowest concentration level, and perhaps at levels where the damage is small compared to the benefit from pollution abatement, forests can be effectively used as sinks for some types of air pollutants. The effective use of forested green belts around urban and industrial areas depends on absorption at these pollutant concentrations.

The amount of a particular pollutant that will be absorbed by the forest is related to the atmospheric processes and source geometry that affect the delivery of the pollutant to the forest and the type of interaction that takes place between the forest and the pollutant. The simplest source geometry is a dispersed source, which is approximated by many small closely-spaced sources. This arrangement leads to a pollutant concentration near the forest, which varies slowly in time and space. For this kind of geometry, pollutant uptake can be treated as one-dimensional, vertical diffusion with a quasi-steady-state boundary concentration. It is one of the simplest absorption geometries for a forest and is the case dealt with in this paper. More complex cases include absorption under plumes or multiple plumes that have rapidly changing pollutant concentrations in time and space and must be studied by using more complex three-dimensional analyses.

The types of interactions between the forest and a particular pollutant depend on the chemical and physical reactions between the pollutant and forest vegetation and soil. The common gaseous pollutants can be grouped roughly according to their physical and chemical reactions with the forest. Some pollutants are essentially unabsorbed by the vegetation, while other pollutants react with plant and soil surfaces or are metabolized inside the plant at a rate that may maintain a steady-state uptake for fairly long periods of time. Intermediate to these two types of pollutants are the pollutants that react transiently by adjusting to new equilibrium concentrations in the plants or soil when external pollutant levels change.

Sulfur dioxide is an example of a pollutant that is actively metabolized by plants and can have steady-state uptake rates for fairly long periods of time when the atmospheric concentration stays below 7 parts per hundred million by volume (pphmv) *(Martin and Barber 1971)*. Therefore its uptake rate by vegetative surfaces can be calculated by using a steady-state, one-dimensional model when the source of sulfur dioxide is of a dispersed nature.

THE MODEL STRUCTURE

A model designed to provide an estimate of pollutant uptake must describe the response of the vegetation-atmosphere system to the environment as it is related to three types of processes: (1) atmospheric diffusion, (2) diffusion near and inside the absorbing plant, and (3) the physical and chemical processes at the sink on or within the plant. The atmospheric-diffusion processes are the result of turbulent eddies, which are related to the state of the atmosphere and the physical structure of the underlying surface. One-dimensional, steady-state atmospheric diffusion with a sink term is described by the equation:

$$\frac{\partial}{\partial z}\left(K\frac{\partial C_a}{\partial z}\right) + S_c = 0 \qquad [1]$$

where

K = The turbulent diffusivity for mass transfer.

C_a = The pollutant concentration (mass/volume) in the air.

z = Height above the ground.

S_c = Sink strength at height z.

The sink strength term is often zero for many pollutants in the atmosphere above the stand. Within the vegetative canopy it is the divergence of the absorption by the vegetation with height.

In the vegetative canopy, the turbulent diffusivity is a function of eddy size and the fluctuation velocity with which the eddies move. The eddy size or equivalent mixing length must be no larger than the open space available for rotation in the stand. The largest openings are the spaces between the individual trees. Smaller eddies are generated in the wake of canopy elements such as leaves or branches. The fluctuation velocity, which can be visualized as the speed with which the eddies rotate, is usually assumed to be proportional to the shearing stress at any level in the canopy. The defining equations are *(Cionco 1965, Takeda 1963)*:

$$\tau = \rho K_m \frac{du}{dz} \qquad [2]$$

$$\frac{d\tau}{dz} = \rho C_d \frac{dA}{dz} u^2 \qquad [3]$$

$$K_m = \iota\sqrt{\Gamma\rho} \qquad [4]$$

where

τ = Shearing stress.

ρ = Density of air.

K_m = The turbulent diffusivity for momentum transfer.

u = Wind speed.

C_d = Drag coefficient of the canopy surfaces.

A = The surface area of the canopy.

ι = The mixing length for momentum transfer.

Equations 2, 3, and 4 can be arranged for a simultaneous integration with height providing values of shearing stress, wind speed, and momentum with height, given a means of determining the mixing length. The procedure presented here used the equation

$$\iota = \iota_c X_s + k \bar{S}_p (1 - X_s) \qquad [5]$$

where

ι_c = Mixing length inside the crown.
X_s = Relative cross-sectional crown area at a particular height.
k = Von Karman's constant ($\simeq 0.35$).
S_P = The average distance between tree crowns.

The spaces between elements within the crown are small compared to the spaces between crowns at most heights in the stand, and thus the values of mixing length inside the canopy are also small, tending to make the effect of the first term on the right-hand side of equation 5 small compared to the second term.

In the turbulent boundary layer above the canopy and in sections of the canopy where there is little surface area to produce drag, equations 2 through 4 can be greatly simplified. In these regions the shearing stress is approximately constant, and the divergence of shear is nearly zero. The value of the mixing length changes approximately linearly with height from the reference height where the shearing stress becomes constant. The constant of proportionality used in the calculations presented later was von Karman's constant ($\simeq 0.35$). In the region of the boundary layer above the stand, this value must be corrected to take into account the effect of buoyancy caused by the exchange of sensible heat at the forest canopy. The correction is calculated by using the equations derived by Businger et al. *(1971)* and Paulson *(1970)* and a value of sensible heat flux determined by a surface energy balance, using the Penman-Monteith formula *(Monteith 1965)*.

The sink strength term in equation 1 is determined by the diffusion into the sink area and the absorption process. The diffusional process near vegetative elements is proportional to the concentration gradient and inversely proportional to the series of diffusional resistances in the flow path. In contrast to atmospheric diffusion, which is dominated by turbulent processes, the diffusion near the sink is largely molecular in nature. For materials like sulfur dioxide, which are absorbed inside the canopy leaves, these relationships are expressed by the equation:

$$S_c = \frac{dA}{dz}\left[\frac{SC_a - C_i}{S\ (r_a + r_s) + r_i}\right] \qquad [6]$$

where

S = The solubility of sulfur dioxide in the cell water.
C_i = The concentration of sulfur dioxide at the sink.
r_a = The leaf boundary layer resistance.
r_s = The leaf resistance associated with diffusion through the stomata in the leaf epidermis.
r_i = The diffusion resistance associated with the cell walls and the cytoplasm.

The boundary layer resistance is proportional to the square root of the leaf aerodynamic length divided by the wind speed. The stomatal resistance is often a complex function of light intensity, temperature, and water stress. When the water uptake from the roots is not limited by soil-water stress, a reasonable approximation of stomatal response can be calculated from *(Gaastra 1959)*:

$$r_s = a + \frac{b}{I + I'} \qquad [7]$$

where

a,b,I′ = Empirical constants.
I = Light intensity incident on a leaf.

The light intensity incident on a tree leaf will be a function of the angle of incidence of the light, the light intensity above the canopy, the leaf angle, and mutual shading of leaves in the canopy. These are incorporated in the model by using an exponential decay of direct beam and diffuse light with cumulative leaf area into the canopy. This results in estimates of the area in direct beam light and of the intensity of direct beam and diffuse light at any given height in the canopy. Separate resistances based on sunlight and shade intensities are calculated, and a weighted mean resistance based on the relative area in direct sunlight and shade at a given height in the canopy is used in equation 6.

The internal resistance in equation 6 is associated with diffusion through the liquid cell cytoplasm. The value of this resistance and its variation are difficult to determine. We have made an estimate on the basis of internal diffusion resistances calculated from photosynthesis data. The data used were from a series of experiments on phytotron-grown loblolly pine seedlings *(Gresham 1972).* The calculation of resistance averaged very close to 20 sec/cm *(Sinclair 1972).* This value is higher than is often found in other experiments. However, since the objective of this simulation is to evaluate the potential of forests as sinks for sulfur dioxide, we decided to use this value, which gives a conservative estimate of absorption.

The solubility of sulfur dioxide in water is very high; therefore the amount going into solution in the cytoplasm of the leaf cells should be large. The mechanism for sulfur dioxide solubility has two components: a reversible chemical reaction converting the gas to soluble sulfurous acid, and normal gas solubility in a liquid. The total equilibrium solubility is given by the equation

$$S = \frac{1}{S_g} + \frac{-H_c + \sqrt{H_c^2 + 4 K_s C_i / S_g}}{2 C_i} \qquad [8]$$

where

S_g = The gas solubility (Henry's law) constant.

H_c = The hydrogen ion concentration.

K_s = The equilibrium constant for the sulfur dioxide - sulfurous acid reaction.

C_i = The concentration of sulfur dioxide in the air at the air-liquid interface.

At a temperature of 25°C, the Henry's law constant has a value of 0.0332, and the equilibrium constant is 0.0130 moles/liter *(Johnstone and Leppla 1934).* The values of both these parameters, which are very temperature-dependent, are given over the temperature range of 0°C to 50°C in Hales and Sutter *(1973)*, who also provide a correction factor that must be used at very low values of atmospheric sulfur dioxide concentration.

The internal sulfur dioxide concentration at the sink site in the absorbing cells is related to the nature of the absorption process. Since sulfur is a metabolite of plants, it is reasonable to believe that at least some part of the absorption process is from the synthesis of organic sulfur compounds. Faller *(1972)* has shown that all of a plant's sulfur requirements can be supplied by foliar absorption of sulfur dioxide. In fact, this will be the preferred source for the aerial organs, given the choice of translocating sulfate compounds from the soil or using sulfur dioxide absorbed from the atmosphere. The level at which this type of reaction becomes saturated can be estimated from experimental data. Martin and Barber *(1971)* have shown that the absorption rate versus atmospheric sulfur dioxide concentration of a narrow hedge is linear up to a concentration of 6.0 parts per hundred million by volume (pphmv) where there is a sharp break above which the absorption rate is constant. Bennett and Hill *(1974)* present data showing that there seems to be no additional metabolic cost, as measured by depressed photosynthetic rate, in barley at atmospheric concentrations of 5 pphmv, but there was a reduction of 2 percent at 10 pphmv. Roberts *(1974)* indicates that a *Pyracantha* seedling can continue steady-state absorption of sulfur dioxide for more than 6 hours at an atmospheric concentration of 100 pphmv.

The conclusion that can be drawn from these studies is that the absorption mechanism is not saturated below values of 5 pphmv and may be able to remain unsaturated for some species above this level. Since National Ambient Air Quality Standards for the United States are 3 pphmv on a yearly mean and 14 pphmv for the 24-hour average, the absorption by forests will often take place under conditions where the metabolic uptake is not saturated. Under these circumstances it seems reasonable to assume that the concentration at the uptake site approaches zero.

Equations 1 through 8 are the basic relationships needed to model the uptake of sulfur dioxide by forest vegetation. The only additional information is the boundary conditions appropriate to a particular environment.

MODEL IMPLEMENTATION

The equations of the model were coded in the Continuous System Modeling Program (CSMP) developed by IBM *(1972)*. This language was chosen over more general-purpose, higher-level languages like FORTRAN or ALGOL because of the large library of subprograms used for systems simulation that are part of the compiler. The leaf area, crown cross-section, and solubility functions were entered as tables, and a standard linear-interpolation program was used to find the values at the appropriate heights and temperatures in the stand. Integration of equations 1, 2, and 3 was accomplished by using a fixed-step Runge-Kutta routine. Integration was started at the bottom ($z=0$) of the stand with values of sulfur dioxide flux, sulfur dioxide concentration, wind speed, and shearing stress. Integration to the highest point desired provided values of these same variables at the upper boundary. It was arbitrarily decided to set upper boundary conditions of sulfur dioxide concentration and wind speed. The sulfur dioxide concentration and the shearing stress at the bottom of the stand were varied until values were found that produced the desired values of sulfur dioxide concentration and wind speed above the stand.

In addition to the boundary values needed for the integration and the tables of leaf area and tree cross-sectional area, other user-supplied inputs are needed to run the program. The leaf aerodynamic length, the constants of the stomatal function, and the other stand data were estimated from a detailed study carried out in a loblolly pine stand as part of the U.S. International Biological program (*Higgenbotham 1974, Gresham 1972, Murphy et al. 1973*).

An energy balance is calculated for the stand to provide values of sensible heat flux for the calculation of diffusivities for mass transfer in equation 4. Input for the energy balance is the incident solar radiation, the incident terrestrial sky radiation, the air temperature, and air humidity above the stand. Two standard cases have been calculated, using idealized values of the climatic input which closely match the average conditions for the coldest and hottest months of the year at the Savannah River Plant, Aiken, South Carolina. The radiation balance is calculated by using the earth-sun radiation geometry for the 15 January and the 15 July to provide estimates of incoming short-wave radiation. Brunt's equation was used to provide estimates of incoming terrestrial sky radiation (*Sellers 1965, chapters 3 and 4*). The net radiation calculated by this method is partitioned between sensible and latent heat transfer by using the Penman-Monteith equation (*Monteith 1965*). Daily air temperature and dew-point temperature (humidity) vary sinusoidally with lags of 3 hours and 6 hours behind the solar-radiation maximum. Values of the required stand structure and climatic data for the two stand conditions are given in table 1.

Table 1.—Input data

Parameters	January 15	July 15
Stand parameters:		
Leaf area index	6.0	9.9
Aerodynamic leaf length (cm)	0.1	0.1
Constants of stomatal resistance equation a (sec/cm)	3.4	3.4
b (sec-ly/cm-min)	0.19	0.19
I' ly/min	0.003	0.003
Drag coefficient of leaves	0.02	0.02
Climatic parameters:		
Average air temperature (°C)	7.9	27.4
Amplitude air temperature (°C)	6	6
Average dew-point temperature (°C)	2.5	21.8
Amplitude dew point temperature (°C)	2	0.5
Wind speed (cm/sec)	260	175
Day length (hr)	8	12

RESULTS AND DISCUSSION

The results of simulations for 2 days representing climatologically average clear days during January and July at the Savannah River Plant site near Aiken, South Carolina, are illustrated in figures 1 and 2. The diurnal patterns are similar. The uptake of sulfur dioxide is at a minimum in the morning and evening and at a maximum sometime before noon. This is inversely related to the average stomatal resistance of the canopy, demonstrating the large effect of this resistance expressed in equation 6. The diurnal pattern of stomatal resistance is a result of our assumption that the resistance is a function of light intensity.

The effect of temperature on the solubility of sulfur dioxide is demonstrated by the uptake maximum occurring before the minimum stomatal resistance at noon. This is because we have assumed that the maximum temperature lags the maximum solar radiation by 3 hours. The solubility of sulfur dioxide in water is inversely related to temperature; thus the maximum absorption takes place at the coincidence of a low stomatal resistance and a high solubility of sulfur dioxide during the cooler morning period.

These results are further illustrated by figures 3 and 4. Figure 3 shows the instantaneous profiles of wind speed, crown cross-section, and sulfur dioxide concentration at 11:00 am of the diurnal simulation shown in figure 2. Figure 4 shows the same conditions except that the radiation inputs to the model are characteristic of a uniformly cloudy sky. The incident solar radiation was lowered from 1.12 ly/min to 0.42 ly/min. The lower incident radiation results in a higher average stomatal resistance at every height in the canopy, lowering the sulfur dioxide uptake by 27 percent. The lower uptake results in higher sulfur dioxide concentrations in the canopy.

A comparison of the total uptake for the January day, 0.29 kg/ha, and the July day, 0.58 kg/ha, shows the type of annual variation that can be expected. As illustrated in figures 1 and 2, one of the sources of this variation is the shorter day length during January. However, even the instantaneous uptake values are lower in January. This is caused by a lower leaf area in January than in July. Although a lower average stomatal resistance might be expected during the winter because of the lower incident solar radiation, this is not the case because there is more shaded leaf area in the denser summer canopy. The effect of the average stomatal resistance is reflected in the fact that uptake per unit leaf area is greater in the January simulation than the July simulation as shown in table 2.

Thus the diurnal pattern of sulfur

Figure 1.—A simulation of the diurnal pattern of sulfur dioxide uptake, net radiation, temperature, and average stomatal resistance for a clear day characteristic of Aiken, South Carolina, during January.

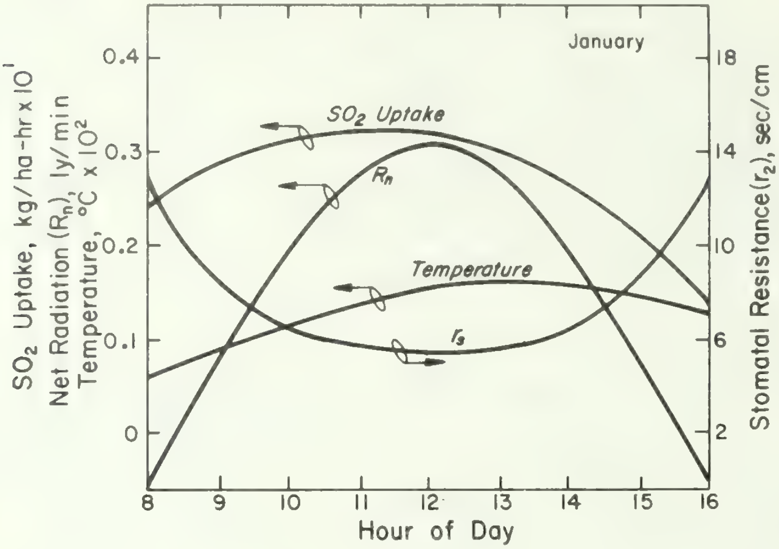
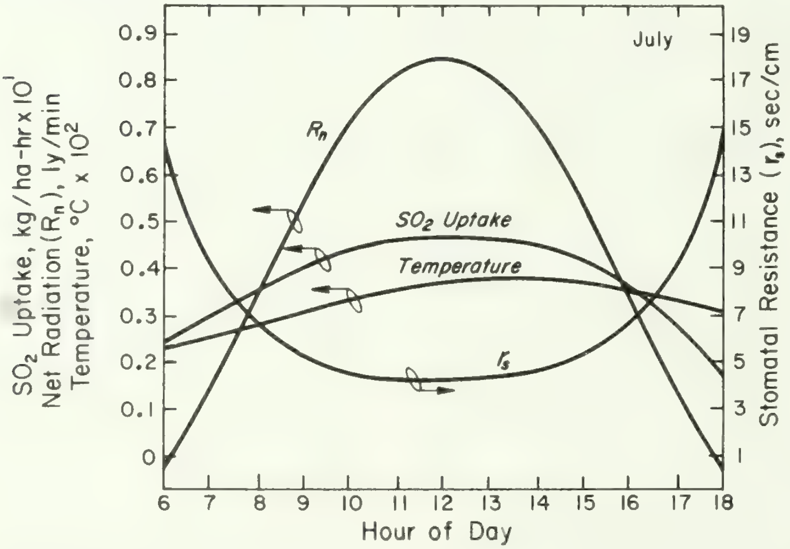


Figure 2.—A simulation of the diurnal pattern of sulfur dioxide uptake, net radiation, temperature, and average stomatal resistance for a clear day characteristic of Aiken, South Carolina, during July.



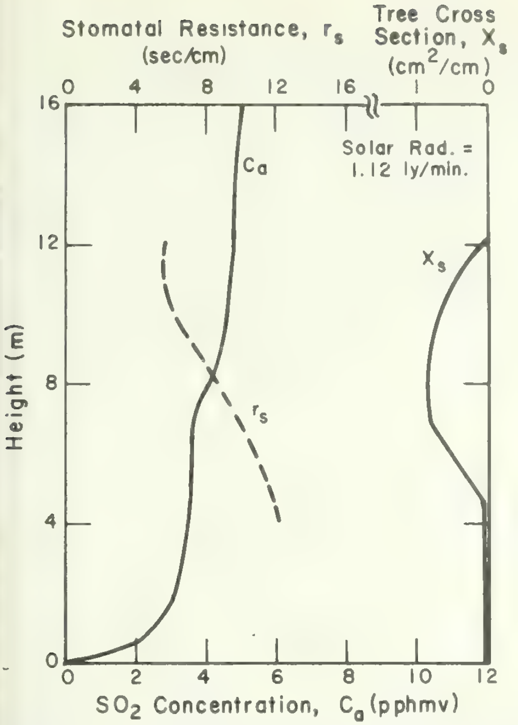


Figure 3.—The distribution of pollution concentration and related tree parameters at high solar radiation.

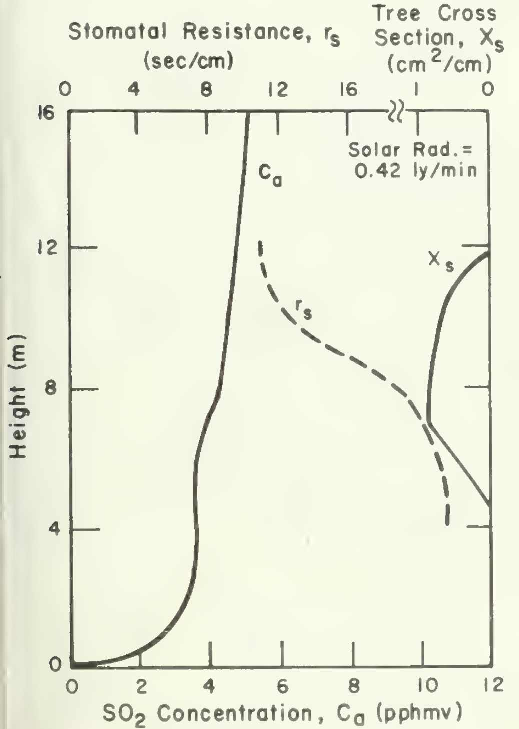


Figure 4.—The distribution of pollution concentration and related tree parameters at low solar radiation.

dioxide uptake reflects the effect of changing solar radiation and temperature on stomatal resistance and sulfur dioxide solubility. The seasonal pattern is affected by these variables and also by the seasonal change in day length and leaf area.

No experimental measurements have been taken under similar climatic and stand conditions, but the uptake rates compare well with those found in laboratory experiments. Table 2 compares the average daily uptake rates from the simulation with the laboratory data of Roberts (*1974*), and Bennett and Hill (*1973*). The results of Bennett and Hill are particularly interesting because an effort was made to duplicate field conditions. The simulated uptake appears to be an order of magnitude smaller than the experimental value. This can be explained on the basis of the high value of the internal diffusion resistance used in the simulation. However, it should be pointed out that the uptake per unit leaf area agrees quite well with the values found for tree species by Roberts, indicating that tree leaves may actually absorb sulfur dioxide more slowly than some other types of vegetation.

Although these results indicate that conifers have a potential for removing sulfur dioxide from the atmosphere, this potential may not be met if climatic conditions are unfavorable. Low light intensity or cold weather can cause stomatal closure and limit sulfur dioxide uptake, as demonstrated in figures 3 and 4. On the other hand, data collected by Martin and Barber (*1971*) clearly show that during periods when atmospheric conditions favor the deposition of dew, this surface water can be a sizable sink for transient absorption of sulfur dioxide.

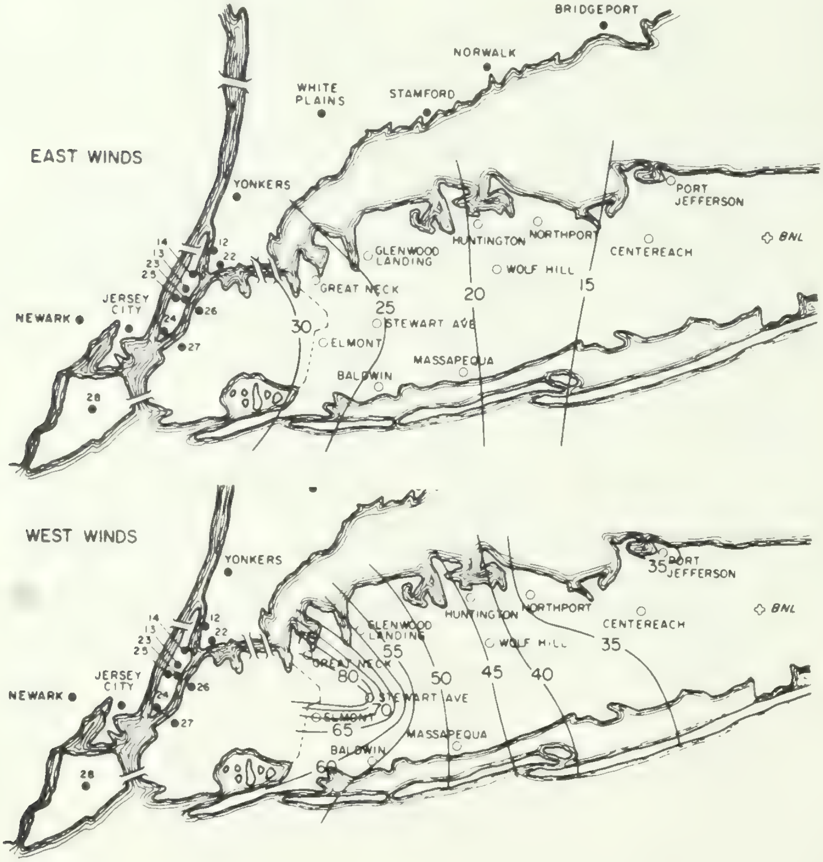
The results of these simulations or similar ones can be used to estimate the uptake of sulfur dioxide over a large area that has trees or crops as a major vegetative component of the landscape.

Table 2.—Comparison of model and experiments

Species	Uptake (kg/ha-hr-pphmv)	Source
Red maple	8.8×10^{-4}	Roberts (1974)
White birch	8.6×10^{-4}	
Sweetgum	7.4×10^{-4}	
White ash	4.6×10^{-4}	
Alfalfa	2.9×10^{-2}*	Bennett and Hill (1973)
	6.2×10^{-3}	
Loblolly pine	7.0×10^{-3}*	January simulation
	1.2×10^{-3}	
	9.8×10^{-3}*	July simulation
	9.8×10^{-4}	

*Based on ground-surface area; other values based on leaf-surface area.

Figure 5.—Mean annual isopleths of sulfur dioxide concentrations with west and east wind over Long Island, New York *(from Raynor et al. 1974).*



This could be forests, parks, farms, or urban areas where the shade trees dominate the surface area. We have made calculations of this type, using the data of Raynor *et al. (1974)* for atmospheric sulfur dioxide concentrations on Long Island, New York (~3276 sq km). Figure 5, redrawn from their paper, shows the average concentrations under two different meteorological conditions. The weighted uptake, assuming the island is completely forested, is 54 metric tons per day for the east-wind case and 256 metric tons per day for the west-wind case, based on the summer values of the simulations shown above.

The sulfur dioxide released to the atmosphere by a large power plant (7,200 metric tons of coal consumed per day) is 280 metric tons per day based on Environmental Protection Agency emission factors (*EPA 1972*). It seems that absorption by vegetation over even large land areas is not significant compared to the output of large power plants. However, if an advanced pollution-abatement method such as catalytic conversion is used, the actual output will be closer to 28 metric tons per day. Under these conditions the forest could absorb a significant portion of the sulfur dioxide present from nine power plants when meteorological conditions are favorable.

Optimum management of forest buffers around urban or industrial areas will be complicated by the effects of diurnal and seasonal variation in absorption. Ideally the pollutant emission could be timed to periods of optimum absorption by the forest; however, in most cases this is not practical. The more attractive alternative seems to be the development of a forest type that has good absorption characteristics during most of the year. Year-round uptake may not be possible in all climates. In the southeastern United States it is possible to grow large areas of coniferous species that have good sulfur dioxide absorption characteristics throughout the year. In colder or drier climates, vegetation uptake may not be as suitable because the major type of vegetation is deciduous, and the conifers have very slow metabolic rates at temperatures below freezing.

Therefore it seems that practical use of forests for air-pollutant sinks must rely on a combination of the proper species grown in the proper climate, with delivery of the pollutants at concentrations and times that favor uptake. However, even under less-than-optimum conditions, forests play an important role in pollution abatement. If the inclusion of a park or natural area in an otherwise urbanized space will decrease sulfur dioxide concentration during half the days in the year, this may be a very desirable use of this space when considered as part of a multipurpose park system.

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HUMAN PERCEPTION, SOCIAL FACTORS, AND ESTHETICS OF METROPOLITAN ENVIRONMENT

Ecology of an Urban Park

by DEREK J. COLEMAN, *president, Ecologistics Limited, Kitchener, Ontario, Canada.*

ABSTRACT.—A controversial issue in the city of Kitchener, Ontario, involves the proposed extension of a boulevard through Lakeside Park. A study of this proposal revealed several facets of human interrelations with an urban park. Most important, there was a large gap between the perception and the reality of environmental quality. This has several practical implications in planning parks in the city.

LAKESIDE PARK in the city of Kitchener, Ontario, (population 125,000) has been the center of controversy for almost a decade. To complete the network of major arterial roads in a section of the city, it will be necessary to construct a four-lane road through the park. Local residents, citizens groups, politicians, and municipal employees have been embroiled in lengthy debate on the issues. This is a report on some of the findings of a consultant's study of the issues.

In this case man is the significant determinant of the environmental parameters. This introduced a new element, because man's perception of the environment became the issue. There was a large gap between what was perceived to be the status of the environment and the actual case.

Lakeside Park is an area of 32 acres of varied vegetation and landscape. Of special prominence is a 4-acre lake in the middle of the park. Physically, it would be possible to avoid the lake in constructing the road. However, the potential destruction of this little gem of nature became a heated issue. The debate involved the lake, vegetation, wildlife, and recreation.

The study reported here included an examination of the status and interrelations of the physical and biological factors of the environment and an analysis of the park and its users.

THE LAKESIDE PARK ENVIRONMENT

Geology and Groundwater

This part of southern Ontario has been subject to several glacial advances from different directions. The most recent glaciation occurred during the Wisconsin period, 10,000 years ago. Kitchener is on the edge of a large interlobate moraine (the Waterloo Sand Hills), and typical conditions for this landform exist in Lakeside Park. Underlying deposits are varied in texture, and the general topography is rough. The lake itself is a kettle formation, resulting from the depression formed by a large mass of ice.

The park area experienced two periods of glaciation separated by a period during which lacustrine clays were deposited. The material deposited during the first glacial period contains large quantities of sands and gravels accumulated to a thickness of 50 to 150 feet over the underlying bedrock. These deposits are water-bearing and are tapped by three municipal wells within the park. Lacustrine clays overlie this aquifer. The clay is, in turn, overlain by organic deposits in the immediate area of the lake and by glacial outwash materials beyond the lake.

The deposits immediately beneath the lake possess a very low permeability, providing a basin in which waters collect to form the lake. These deposits also act as a aquiclude (confining the aquifer below). Observation wells established that the lake is not a perched water table, as had been feared, but that the groundwater system is continuous with depth.

Water Supply and Quality

The lake as it presently exists has a surface area of 3.7 acres and ranges in depth down to 22 feet. As natural processes occur, the lake will gradually fill in with organic materials and waterborne solids. The total land area draining into the lake is 150 acres. The drainage basin is urbanized (except for the park), and three storm sewers discharge into the lake.

The total annual average rainfall in this area is 32 inches. This will result in approximately 150 acre-feet of water discharging to the lake. Drainage from the lake also drains into a small creek when the water level is above a certain elevation. For the rest of the year, there is no outflow. The water level in the lake drops below its outlet during dry periods because of evapotranspiration.

The lake in the park is one of the most eutrophic bodies of water in the Province. Eutrophication is a process whereby the nutrient level or fertility of a water body increases naturally as it ages. These nutrients stimulate the growth of aquatic plants, particularly algae, and the familiar problems of odor, weeds, and a deterioration in esthetics result. Eutrophication may arise through normal runoff and decomposition processes. The addition of storm sewage and runoff from fertilized lands accelerates the process.

Some of the water-quality data collected during study of the lake by the Ontario Ministry of Environment revealed coliform bacteria counts, nitrate nitrogen levels, and organic and ammonia nitrogen levels above the allowable limits for recreational use.

Nuisance water-pollution problems were identified as well. In several samples, the amount of oxidizable organic matter as measured by the BOD_5, COD, and volatile solids tests was greater than that normally found in surface waters. This suggested a high level of decomposition in the lake and the possibility of deoxygenation during nighttime hours. In the hypolimnion, with temperatures several degrees lower than the surface, the dissolved oxygen concentration approached 0 mg./1. Chloride ion, a common indicator of contamination by man, was measured in relatively high concentrations.

The major source of contamination in the lake seems to be storm-sewer discharges during periods of runoff.

Soils and Surficial Sediments

An examination of the soils and surficial sediments of the park revealed that the developed soil profile had been disturbed throughout most of the park.

Two large areas of fill material were discovered. Investigation of the filled area on the east side of the park revealed that this area had once been mined as a gravel pit and subsequently was filled with wastes and debris. The other area of fill was more recent. The upper park consists of stratified sands and fine gravelly sands, which have been remolded at some time.

Erosion of the steep embankments,

particularly on the eastern side of the lake, has been severe at various periods in the past. This is substantiated by the occurrence of soils consisting of 12 to 30 inches of sand loam and fine sands overlying 5 to 6 feet of organic and marl deposits.

Vegetation

Examination of the vegetation of the site, on air photos and in historic records, revealed that major changes had occurred in the past 25 years. Most notably, Dutch elm disease, land clearance, and filling have resulted in many large trees disappearing. The park does, however, support a diversity of vegetation communities from pond to marsh to upland. In a botanical survey of the site, 213 species of plants were identified.

All the vegetation in the park has been subjected to the influences of man. Characteristically, the vegetation is in secondary succession following severe disturbance. As a result, the canopies of most of the stands are open, with dense growth beneath. Many shrubs are present.

The east side of the park supports more natural stands of vegetation. The west and north sides are predominantly maintained lawns, except in the immediate area of the lake.

Wildlife

Inventories of birds and mammals of the park revealed a pattern of individuals and populations that related strongly to the vegetation structure. Thirty-nine species of birds were identified in the park. The diversity of species on the east side of the pond was identical (24 species) to that on the west side. Though the number of species on each side was the same, there were six species seen on each side that were not observed on the other. The east side had areas of denser tree canopy and more edge between woods and fields, thus attracting rose-breasted grosbeaks, eastern wood peewees, field sparrows and indigo buntings. The west side possessed more open fields, thus attracting species like kiildeer.

The diversity of bird species was related to the structural and botanical diversity of the vegetation. In the west, the cultivated landscape attracted only seven species, though it comprised 84 percent of the area. The more vegetationally diverse sections had 22 species on 16 percent of the area. The four vegetation areas with the most bird species contained a mean of 55 plant species each, which was almost twice as great as the mean for the four areas with the lowest number of bird species. The valuable habitats for birds were identified as those with both the largest amounts of high and low canopy and with the greatest vegetation diversity.

The most common species of mammals trapped in the park surveys were the white-footed mouse, the short-tailed shrew, and the meadow vole. Six of the seven vegetation areas in which small mammals were found are on the east side of the pond. All species prefer the dense herbaceous growth of the more natural environments. This is shown by a comparison of the mean percentage of shrubby cover in the vegetation areas where small mammals were captured (70 percent) with those areas where small mammals were not captured (31 percent).

Recreation

A survey of park users and activities showed several interesting patterns. The park attracts people from only a limited surrounding area, approximately ½ mile for most users. It serves the function of a neighborhood park, providing space for recreation to meet local demands. The people who do use the park do so frequently, averaging 4.8 visits per week. These people are predominantly children aged 1 to 12 and people over 65.

Observations on the spatial patterns

of the summer users produced interesting patterns. The highest concentration of users (32.7 percent) was in the playground off in one corner of the park. Walking, jogging, and the water-related activities showed medium levels of participation. Passive activities, such as sitting and sunning, bird-watching, and picnicking showed low levels of participation. The avoidance of the natural areas and attraction to facilities was obvious.

THE PARK ECOSYSTEM

When these various factors and conclusions were examined as a whole, several important conclusions became evident.

1. People focused on the lake as the significant natural feature of the park. It was perceived to be (by some knowledgeable people) very sensitive to the environmental effects of the proposed road. In fact, however, the lake was in an advanced state of eutrophication, in which many water-quality parameters were above recommended levels for contact recreation. The primary source of water to the lake was storm-water runoff. This rich environment had many benefits because it supported luxuriant aquatic vegetation and high populations of coarse fish for children to catch.

   This suggests that we do not necessarily require the achievement of a high-quality body of water for it to serve a significant amenity or recreation function. The eutrophic natural condition is stable and inexpensive when compared to the cost input necessary to artificially maintain marginally better conditions.
2. The terrestrial environment (soils, vegetation) of the park had been completely altered by man's actions in the past. The vegetation was predominantly early successional weed, shrub, and tree communities — not what one would consider particularly significant. However, because of its structural and vegetational characteristics and the diversity of habitat, the vegetation attracts an unusual number of bird species.

   Thus, although not important in itself, the vegetation of an area—even of 10 or 15 acres—can relate to substantial bird populations and provide a significant environmental resource within a confined space.

   One issue for environmental philosophers that is raised by this case develops from the preservation of the conditions in the park. If allowed to progress long enough, a more uniform and less attractive environment for birds will result. Thus, are we then justified in altering the natural processes to maintain a desirable situation that would extinguish itself?
3. Even though the natural features of the park were perceived as being its outstanding characteristic, particularly by the vocal environmental groups, the average park user did not attempt to come in contact with the more natural areas — except for the young who played on the pond edge. The patterns of man and nature did not overlap. The local naturalists were such a low percentage of park users that they were not recorded during the surveys.

   Thus, in planning for nature in our parks one must ask for whom certain elements are preserved.

   Since the spatial patterns of the recreationists and nature did not conflict in this case, it suggests that careful planning can resolve problems of incompatibility.

Man-made New Orleans: Some Interactions between the Physical and Esthetic Environments

by RONALD F. LOCKMANN, *assistant professor, Department of Anthropology and Geography, University of New Orleans, Lakefront, New Orleans, La. 70122.*

ABSTRACT.—The relations between the physical environment and esthetic dimensions of the New Orleans cultural landscape are examined. The esthetic characteristics associated with New Orleans urban morphology are examined with respect to possible constraints by the physical environment. Salient townscape features such as street grid system, surface-drainage network, and spatial features of selected residential neighborhoods provide instances that demonstrate the varying levels of physical environmental impingement upon the esthetic landscape.

Because of its close, if not abject, dependence upon local building materials and local qualities of site, the city epitomizes the surrounding country and gives a special character to the natural setting. At no moment in its existence is the divorce between the man-made environment and the earth complete.

—LEWIS MUMFORD, *in* *The Culture of Cities*

THE NEW ORLEANS urban complex stands upon what has been termed the flattest, lowest, and geologically youngest site of any major city in the United States (fig. 1). The site has been above sea level for roughly a thousand years, while the most significant human landscape modification has transpired roughly within the past two centuries.

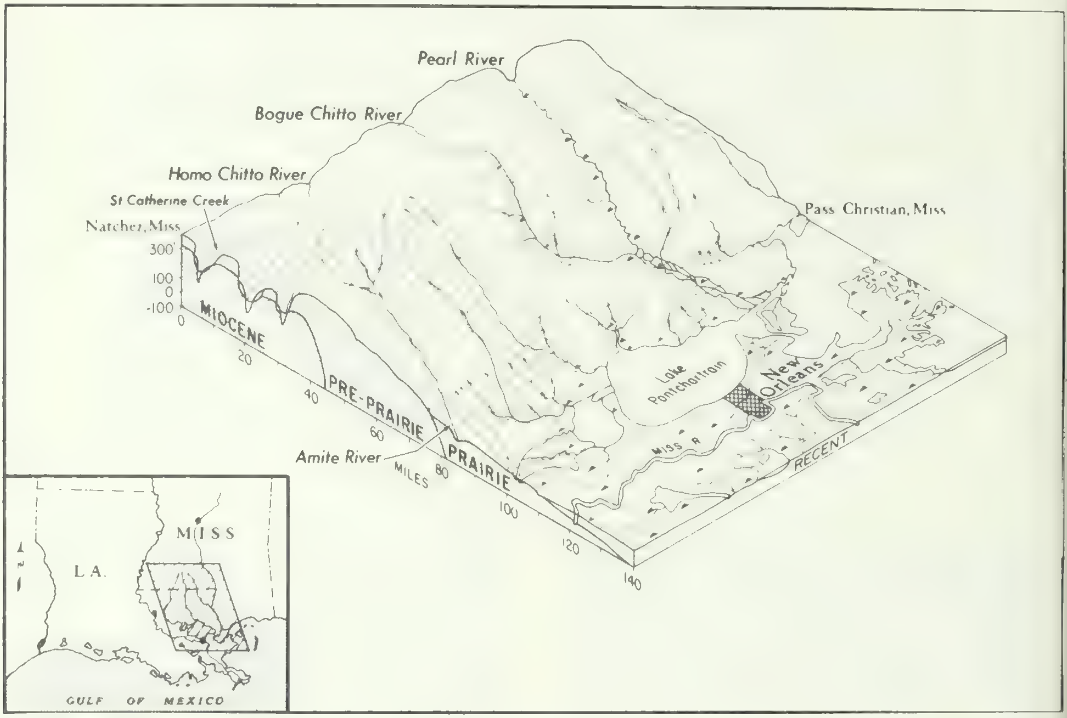
The growing demands for space to accommodate the population of one of the world's major ports have transmogrified the physical landscape of New Orleans so fundamentally that the designation — man-made — applies not only to buildings, roads, and other components of the cultural landscape, but also to the undulations of the land surface itself. Indeed, the processes of site preparation and maintenance (that is, from extreme meteorologic or hydrologic events) have built a virtual walled city that is primarily below sea level, and portions of which, in geological terms at least, are subsiding rapidly.

The visual or esthetic landscape is compounded of the disparate elements of the physical and human scene, and it becomes chaotic and illegible in certain locales as a result of the uneasy symbiosis of man and nature. Especially the street grid, drainage system, and spatial structure of certain residential neighborhoods give visual evidence of the inextricably interwoven physical and human landscapes.

ASPECTS OF THE PHYSICAL MILIEU

New Orleans' global importance as a port followed from its geographical location on the lower deltaic plain of North America's premier river. The "Isle of Orleans" depicted by the eighteenth century cartographer Delisle is reality when one considers that marshlands flank the city's eastern and western edges, and the banks of Lake Pontchartrain on the north and the Mississippi to the south are permanent, though dynamic, physical boundaries. The characteristics of the land surface have long confounded potential residents as well as visitors, as an eighteenth century account affirmed:

Figure 1.—Block diagram illustrating geologic structure and geomorphology of New Orleans region in southeastern Louisiana. Courtesy Dr. Sherwood M. Gagliano.



> At high tide, the river flows through the streets. The subsoil is swampy . . . Dikes have to be built along the river, and houses can be constructed only on piles. Those living in the city . . . feel as if they were living on an island in the middle of a mud puddle. *(Regional Planning Commission 1969)*

The alluvial ridges or levees built by the Mississippi River's overbank flow at high stages provided the highest ground, although they stood no more than 10 or 15 feet above sea level. In addition to the natural levees, less extensive former beach ridges were deposited above the generally sea-level fresh (some brackish) water marshes, while thickets of cypress dominated the swamps. Much of this area, most of the present urban region, is thus below sea level, thereby accounting for the popular concept of a bowl-shaped base on which New Orleans is situated.

The former beach ridges, called Metairie and Gentilly ridges, (also called Metairie Bayou and Bayou Sauvage (figs. 2 and 3) provided the road surfaces, west and east respectively, giving first overland contact to the town of New Orleans.

IMPACT OF HUMAN MODIFICATION OF THE LANDSCAPE

The locale of New Orleans proved attractive for the aboriginal Amerinds who occupied the region for more than 2,000 years. The Europeans realized, as early as 1699, the strategic value of the Bayou St. John portage route between the Mississippi and Lake Pontchartrain. The natural levees were a stable and partially dry foundation for the original settlement's nucleus. Thus the French Quarter is situated on some of the highest ground in the region.

Yet from the very beginnings, the concern for flood control, or protection, by walled dikes was paramount. In 1722, the engineer La Tour urged the

Figure 2.—Regional geomorphology of New Orleans in the Pontchartrain Basin vicinity. From Saucier 1963.

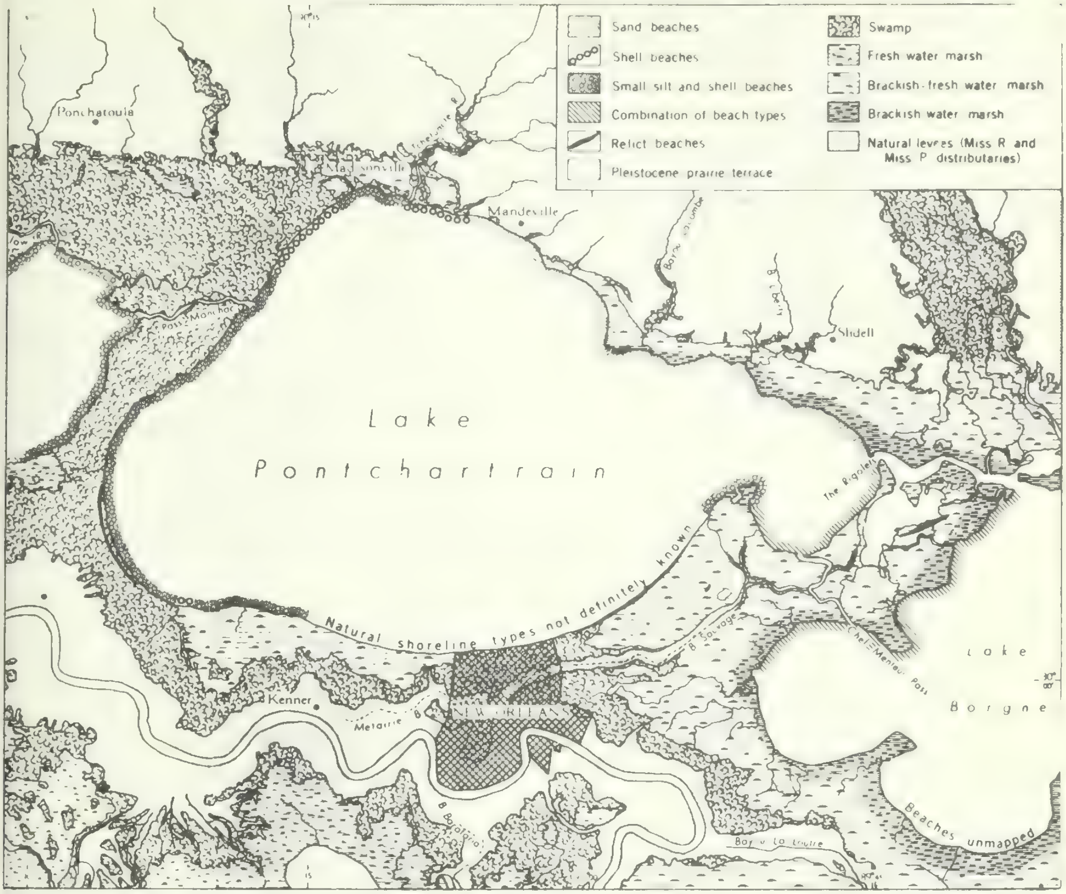
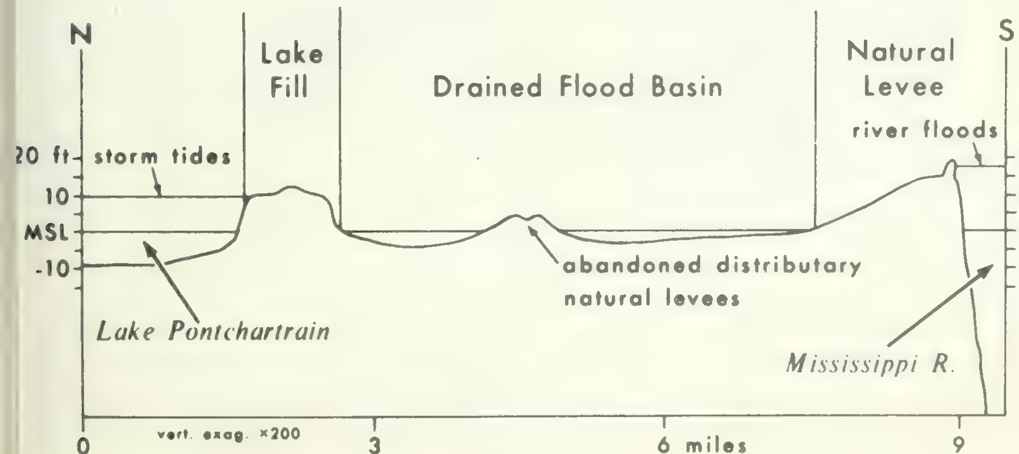


Figure 3.—Typical north-south profile through city of New Orleans. Courtesy Dr. Sherwood M. Gagliano.

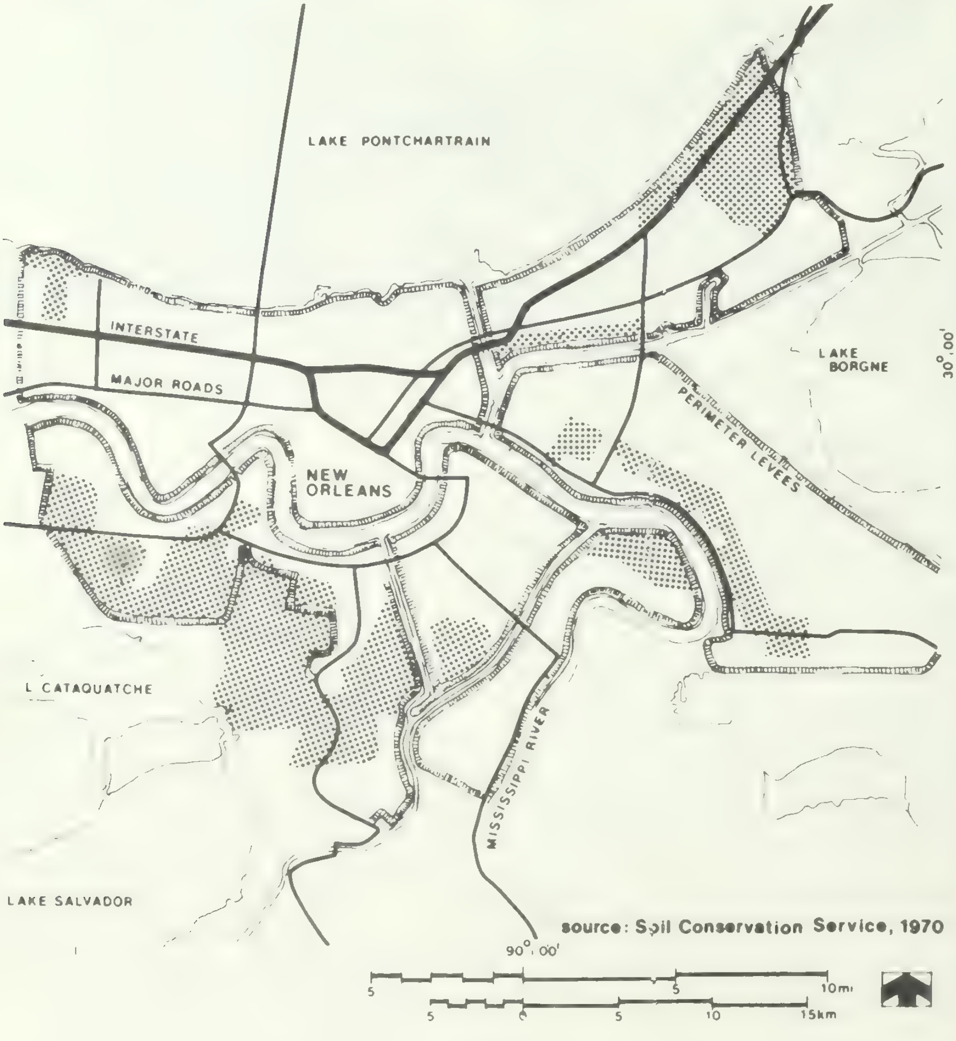


construction of higher and wider dikes than those already being built. And nineteenth century maps clearly depict the correspondence of urban morphology and the higher ground of the natural levees. A Mississippi River Commission report in 1896 indicated that at least half of the land inside the present-day city limits remained swamp and marshland. The nineteenth century saw cycles of levee building and subsequent destruction by major floods.

At present, the Army Corps of Engineers builds the levees in the New Orleans area, and local or parish agencies retain the responsibility for their maintenance. The system consists of levees on both banks of the Mississippi, averaging 25 feet (7.6 m) above sea level. Thus New Orleans' site is likened to a high-rimmed saucer. The levees may keep the river from entering the city, but they have also served to retain whatever water may enter.

The city averages more than 60 inches (150 cm.) of precipitation yearly; and disposal of excess water was one of the historic urban woes in New Orleans (*Jennings 1972*). It was only in 1917, upon the employment of the electric

Figure 4.—Areas surveyed by Soil Conservation Service, 1970, showing soils potentially unsuitable for urban construction. Courtesy Dr. Dan W. Earle.



source: Soil Conservation Service, 1970

screw-type pump, that the swamps and marshes were drained and the city's fringe could advance in subsequent decades through the mid-city district and towards the lakeshore. As recently as the late 1920s, the Lake Pontchartrain shore was, with few exceptions, a swampy isolated expanse with permanent settlements consisting mainly of ramshackle fishing camps (*Filipich and Taylor 1971*). The east and west roads out of New Orleans, on Gentilly and Metairie ridges respectively, contained the preponderance of suburban population. As recently as 1940 New Orleans had, among major American cities, one of the lowest ratios of population residing outside the city limits (*Gilmore 1944*). Since the urban region's population has nearly doubled in the span from 1940 to the present, the main era of extensive wetlands drainage to facilitate residential construction has occurred recently (fig. 4).

LOCAL VISUAL QUALITIES AND THE NEW ORLEANS ESTHETIC LANDSCAPE

Tourism is commonly cited as the second leading industry of the New Orleans economy. Certainly the widely held city image of an uncommonly scenic and distinctively old-world townscape is a part of the lure that attracts large numbers to visit New Orleans annually. The obvious attractions are the French Quarter and the ante-bellum residential Garden District. It may not be readily apparent that these neighborhoods stand on some of the higher ground in the city. Nor is one palpably below sea level in certain adjacent areas.

Reading the local landscape is further complicated by the commonplace realization that the French Quarter's cracked and disjointed sidewalks, an occasional tilted house, or sagging fences in the Garden District are conditions to be expected in historic areas and are hardly unique to New Orleans. Relatively few tourists expend the effort to view any of the dozens of other local neighborhoods or suburban outliers of New Orleans. It is therefore possible, and even easy, to miss the subtle but nonetheless prevalent visual clues and tangible landmarks that epitomize the problems of construction on an unstable foundation.

The New Orleans esthetic landscape is a product of the structures and spaces man has superimposed on a physical base, and yet the very base itself has become a man-made object that gives an overtly distinctive appearance to large sections of the urban region. The intricate interrelation between man's modification of the physical environment and its reciprocal impact on structures and general surface characteristics can be illustrated by a consideration of street patterns, drainage systems, and land subsidence in selected portions of New Orleans.

STREET GRID

The distinctive overall feature of the road pattern of New Orleans as seen from the air or map view is the fan-like layout of streets on that lobe of land enclosed by the crescent bend of the Mississippi River. Adjusted to the configuration of early land-ownership boundaries, the configuration is not a direct response to physical conditions. The more common rectangular or checkerboard street pattern, with roads intersecting at right angles, is characteristic of most of the rest of the New Orleans region and suburbs, except where developers have built winding roads and cul-de-sacs in recent subdivisions.

Spatial or directional orientation is a persistent malaise affecting lifelong New Orleanians as well as tourists. Though this affliction may be understandable in the vicinity of extended curvilinear roads and triangular blocks in the fan-shaped Uptown and Garden District, it is apparently just as common for the presumably more logically arranged rectangular districts. These latter patterns now largely occupy the former open spaces between the network of drainage canals that turned them into dry land.

A popular solution to the complexities of local geography is location fixing with reference to the Mississippi River and Lake Pontchartrain. The location of a residence, for example, is either "riverside" or "lakeside" of, for example, the main interstate highway that bisects much of the urban area (fig. 4). Another local practice to simplify direction giving is the use of the terms "above" and "below" for distinguishing points on either side of a given boundary (particularly streets), generally with reference to the central business district. In the context of a city with considerable sub-sealevel land, this particular local trait is potentially confusing, indicating to outsiders that New Orleanians possess some remarkable perceptual acumen and are intimately aware of the nuances of local topographic undulations. This is most assuredly not true, and "above" and "below" are strictly horizontal references and not elevation indicators.

Passengers in a vehicle or pedestrians who turn off the major commercial and connecting thoroughfares notice the predominantly narrow streets in most of the older neighborhoods. Although narrow streets are hardly a unique New Orleans trait, their prevalence underscores, along with the typically long and narrow lots, that space has been at a premium in this city.

The condition of the road surfaces reflect the stresses of overlaying a differentially sagging foundation. Off the main traffic arteries, warped, cracked, caved, and potholed road surfaces are common. Yet roads often mark the neighborhood's highest local relief. And in areas lacking some variety of curbing, clam shell and deeply indented mud shoulders further contribute to an overall impression of disarray and instability.

WATER-REMOVAL STYSTEM: CANALS AND DRAINAGE

Street orientation in New Orleans exhibits a strong general correspondence with the drainage network. And since the network provides daily removal in the basin as well as affording drainage for heavy storms and flood occurrences, it is a crucial to the continuance of urban utilization of the site. By 1970 the Parish of Orleans alone boasted 1,400 miles of drainage canals and the 13 pumping stations, probably the greatest aggregation of low-lift pumps assembled anywhere in an equal area (*Carter 1969*), with an aggregate capacity of 17.5 billion gallons (65 million liters) per day.

Canals range in size, some being as much as 80 feet (24.5 m) wide. Features of this magnitude are indeed prominent landmarks and boundaries in the visual landscape. The open canals also assault the olfactory senses when flow is slight, giving false credence to the occasionally published misstatement that New Orleans employs open sewers.

Canals are perhaps less obvious in the older sections of the city, where many were covered, than in the more recent subdivisions, where housing construction followed close upon canalization and covered canals are an unaffordable luxury.

It is terribly easy to underestimate the extent of the New Orleans region's drainage system based on direct observation, but the impact of the system is more profound than keeping excess water from the streets and forming barriers to the flow of traffic. The continued action of the drainage process is fundamental to the gradual lowering of the land surface itself (*Gagliano 1973*). This process, which requires expensive maintenance of the flood-protection landform complex, and the gradual moving and tilting of structures built on the surface of a differentially undulating topography, is among the chief features of the New Orleans esthetic landscape.

LAND SUBSIDENCE: THE CHANGING NEW ORLEANS SCENE

The phenomenon of land subsidence is among the paramount physical processes impacting on urban expansion in the New Orleans metropolitan region. It has been succinctly defined by Saucier (*1963*) as the relative lowering of the land surface with respect to sea level. More recently Earle (*1975*) has pointed out that the term is often invoked with reference to tectonic occurrences over a larger region whereas "settlement" usually refers to a less extensive area and the changing compaction of soil. The term "lowering" is employed in regards to road, building, levee, or other compression of underlying soil. The popular equivalent of "subsidence" is "sinking".

Land subsidence is a global nuisance and many cases have been closely observed and documented. This phenomenon has occurred in London, England; Osaka, Japan; Lake Maracaibo, Venezuela; and Mexico City to name a few notable examples. In Mexico City an exposed well casing in the Plaza de la Republica, originally flush with the surface, was measured at 23 feet (9 m) above the present after about 60 years of use (*Fox 1965, Legget 1973*).

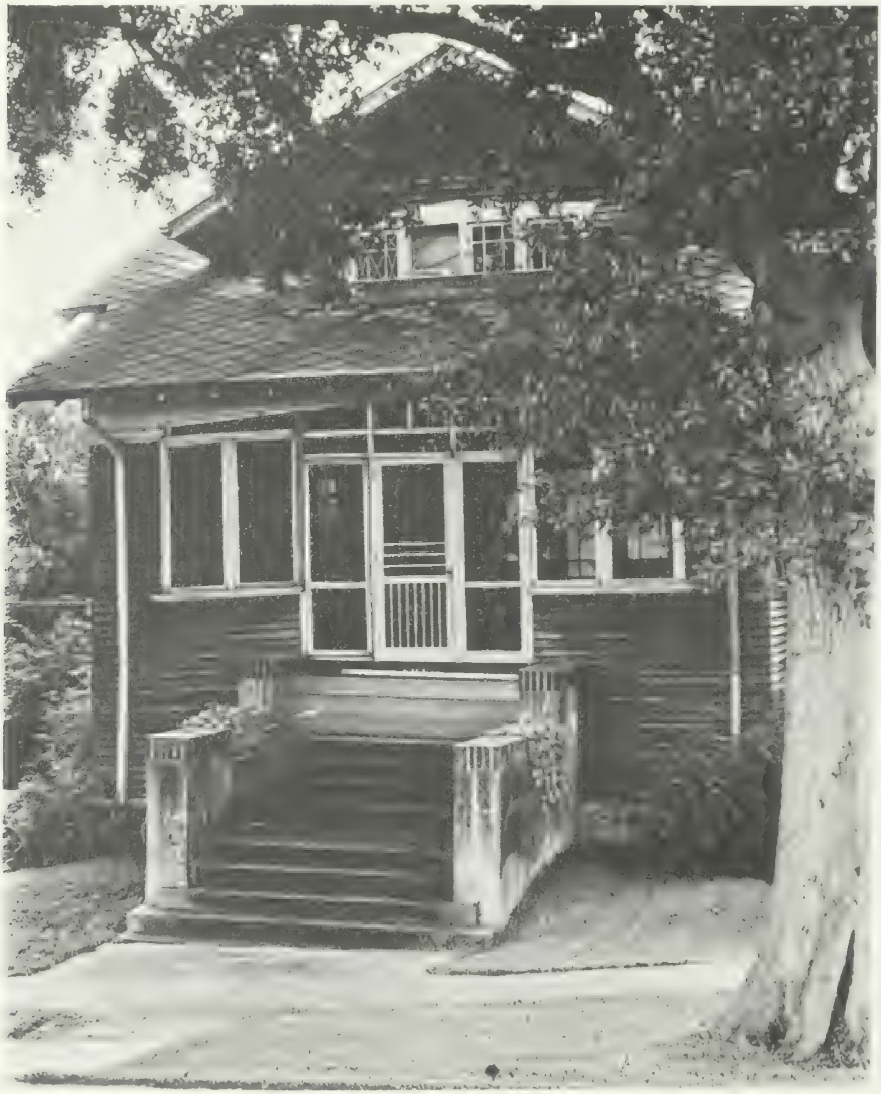
In the United States, land subsidence is by no means uncommon. Owing, perhaps, to the somewhat less extreme nature of land subsidence, New Orleans is not mentioned in most of the standard subsidence literature, although the extent of the local problem is visibly apparent throughout the metropolitan area and especially in a few noteworthy neighborhoods. In the drained wetland regions such as New Orleans, the complexity of organic soils makes it difficult to relate subsidence to a single cause. The major factors impinging on land subsidence rates in New Orleans are: dehydration and shrinking of the deposits; oxidation of organic substances; the drop in the local water table; and excavation for sewers and water lines. Some local soil types may contain 4 to 12 feet of compressible organics, and the water content of humus may be 400 to 700 percent of dry weight (*Soil Conservation Service 1970, fig. 5*). A series of level surveys in the organic soils of the Florida Everglades measured an 8-foot (2.5-m) drop in surface over a span of 50 years of regular measurement (*Stephens and Speir 1970*).

Land subsidence in the New Orleans metropolitan area is prevalent in virtually all neighborhoods, but a few districts in particular epitomize the problematic extremes of this phenomenon. Cracks, broken, and undulating sidewalks; tilted houses and other structures; inclined tree trunks and utility poles; and undulating lawns, and other open-space surfaces are virtually ubiquitous manifestations of the semi-fluid regional substrate.

The older neighborhoods may be relatively less affected, yet in the established districts of Carrollton, Mid City, or Lakeview, each with sub-sealevel areas, scarcely one block exists without numerous visual symptoms of subsidence (fig. 5). In the highest and oldest portions of New Orleans, numerous structures have lasted for many decades with negligible tilt or settlement.

For this reason, foundation support by pilings or caissons are not mandatory for construction in the metropolitan region. On the other hand, the largest structures such as the 60-storied One Shell Square Building or Louisiana Superdome have had steel or concrete pilings extended beneath their foundations to between 100 and 150 feet (31 to 45 m). Most residential construction, employs log pilings about 40 to 50 feet (12 to 15 m) in length, which is generally sufficient to ensure structural

Figure 5.—Residence in 6300 block, West End Boulevard in Lakeview section, New Orleans. Note undulating sidewalk as well as cracked and tilted stairway.



stability in most locations in the region. But since the necessary drainage system tends to lower the previously higher water table, followed by oxidation and compaction, most of the urban complex experiences the effects of subsidence (*Gagliano 1973*). On the formerly sea-level drained marshland on the eastern and western suburban fringes of New Orleans, two subdivisions stand in mute testimony to the extreme and dramatic impact of land subsidence in the region.

LAND SUBSIDENCE: EPITOME DISTRICTS

Village Del'Est is a subdivision in the eastern part of the city of New Orleans, built in an area long avoided for urbanization because of its marshy foundation. The Harold Park section is located in the municipality of Kenner, immediately north of New Orleans International Airport and was built as the population of New Orleans' western suburban fringe expanded during the past 20 years. In the span of time since they have been completed—and there are still vacant lots in both areas—these districts have provided some of the most striking examples of physically and visually blighted portions of the New Orleans area. Tilted structures exposed foundation slabs, cracked walls, drivedays and sidewalks, and leaning fences and utility poles are among the most vivid visual impressions of both of the subdivisions; and few blocks in either one has two adjoining houses without one of these problems.

Few industrious residents have been able to maintain the original appearance of their premises, and many have long since stopped trying. Buying loads of fill soil to bring up levels to original is a prevalent practice in suburban as well as older New Orleans districts, but one truck-load would hardly suffice in Village Del'Est or Harold Park. One section in Kenner experienced sinking of as much as 1 foot in a month's time (*Aquanotes 1975*). The expense of filling large tracts has led developers to disregard realistic estimates of potential subsidence on the drained wetlands underlying these and other subdivisions. In one segment of the Village Del-Est, one 760-acre (308-ha.) plot was filled with 630,000 cubic yards (481,666 m^3) of material to raise the surface 6 inches (15.2 cm) above the original level. To add another vertical foot would have cost the developer $3,030 per acre *(Earle 1975)*. It is thus understandable why the developer estimated that potential subsidence would be 6 inches to 1 foot!

In Harold Park, Kenner, as well as in other locations, some developers reduced their cash outlays by eliminating the foundation pilings. The result is several blocks of moderately to severely tilted houses. The corner of Arkansas and 32nd streets provides one striking

Figure 6.—Residence at corner of Arkansas and 32nd Streets, Harold Park subdivision in Kenner.

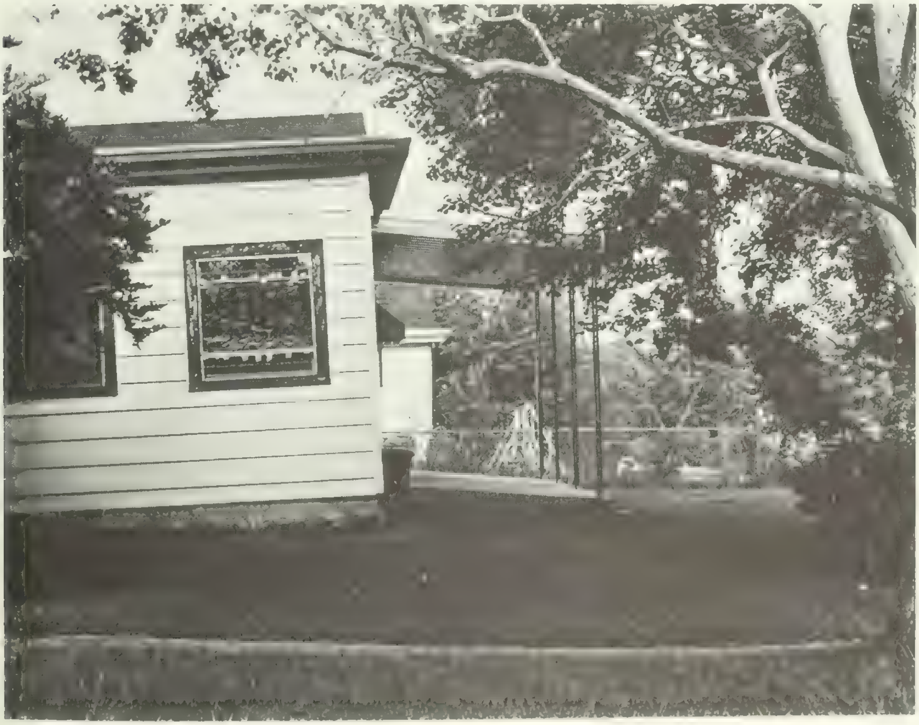


Figure 7.—Residence at 4211 Williams Boulevard, Kenner. Support pilings appear to be stilts. Note incline of unsupported concrete pad.

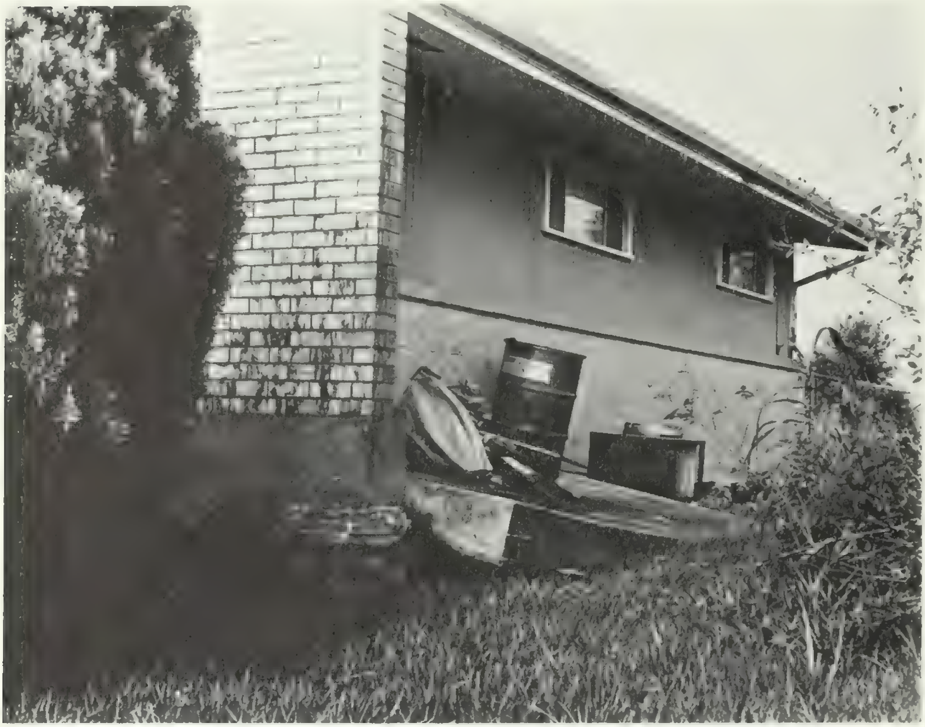


Figure 8.—Residence in 3200 block of Colorado Street, Harold Park subdivision, Kenner.

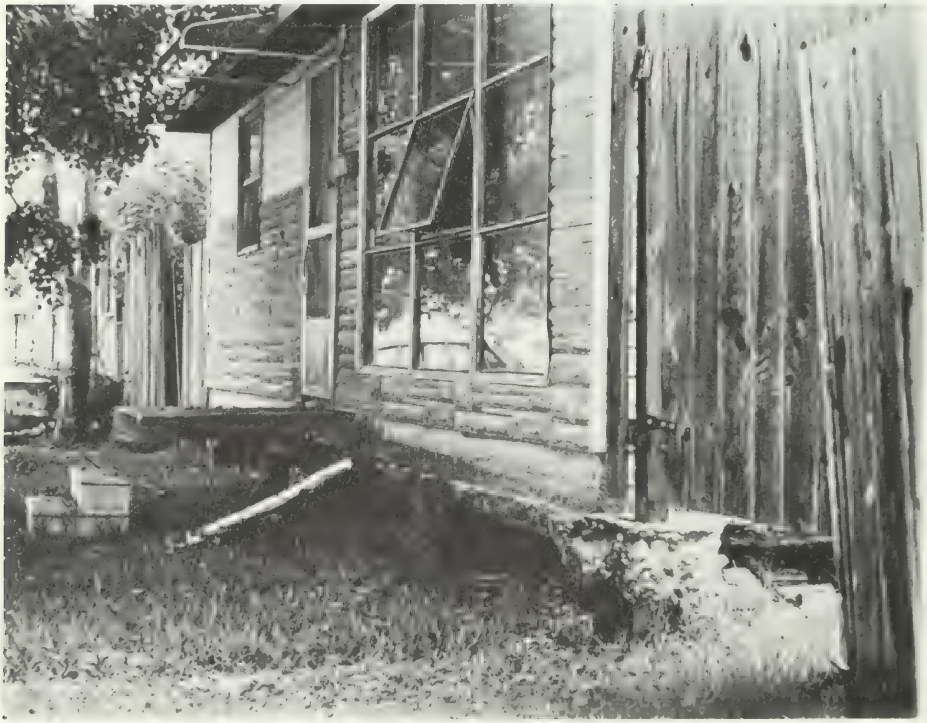
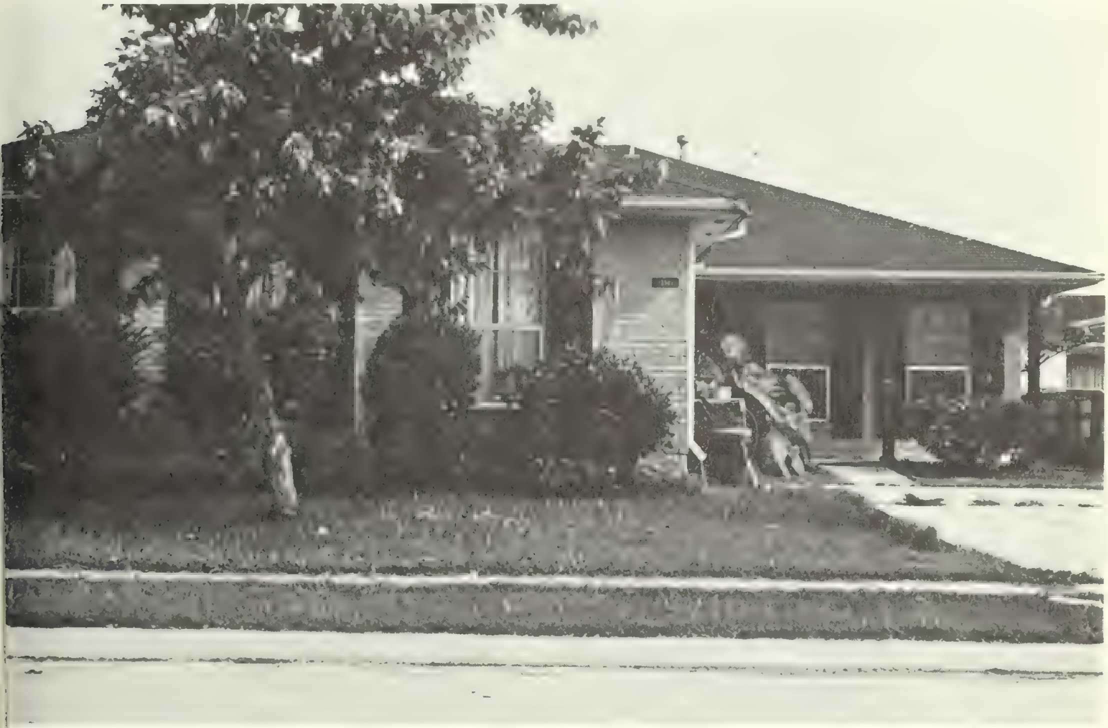


Figure 9.—Residence in 13000 block of N. Nemours, Village Del'Est subdivision, New Orleans. Ornamental plantings obscure exposed foundation bottom directly behind tree.



visual example of structural movement and damage (fig. 6). Even many of the buildings supported by pilings have been affected to the extent that undersides of foundations and even the pilings are above present ground level, giving the appearance of low-level stilt houses (figs. 7 and 8). Some Village Del'Est homes have undergone the same forces, the subfoundation space providing den or nesting sites for domestic animals and wildlife from adjacent marshlands (*Carrier 1975*).

Adroit placement of foilage is sometimes successful in masking the extent of subsidence (fig. 9), although some residents have decided to remove larger shrubbery and trees when soil-creep moved root systems and trunks toward the foundation hole. Piles of earth fill are among the most pervasive of visual landscape characteristics in Village Del'Est. Along many streets, such as N. Lemans, scattered piles of earth fill have formed a hodge-podge of domal and conical hillocks, many at least partially overgrown with tufts of weeds and grass, while some have become overgrown and entirely incorporated into the lawns. The billowy undulations and the welter of unkempt yards, devastated foundations, fences and sidewalks (figs. 10 and 11) combine to invest the esthetic landscape with a chaotic and blighted guise starkly contrasting in extremes with the subdivision's original and intended appearance.

In Village Del'Est, as elsewhere, esthetic environment manifests itself in financial considerations. In Village Del'Est, the average expense per year was calculated to be $120 for about two-thirds of the residents; nearly one-third had expenses in excess of that figure, and some 5 percent of homeowners in the tract reported annual costs of over

Figure 10.—Warped and cracked sidewalk on corner of E. Lemans and Dwyer Streets, Village Del-Est subdivision, New Orleans.

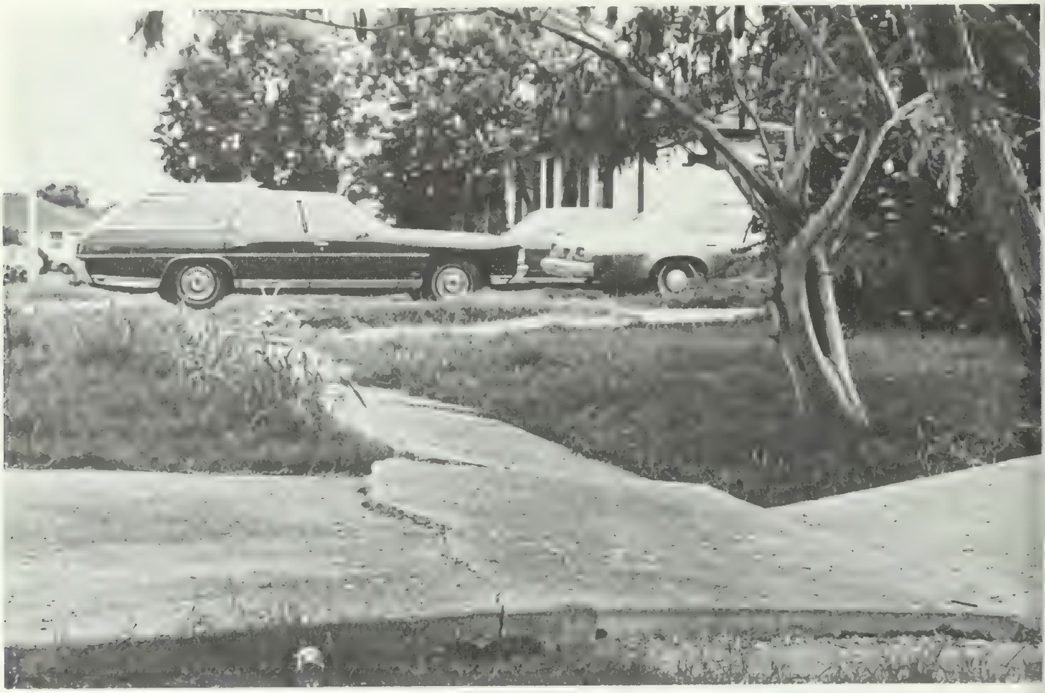
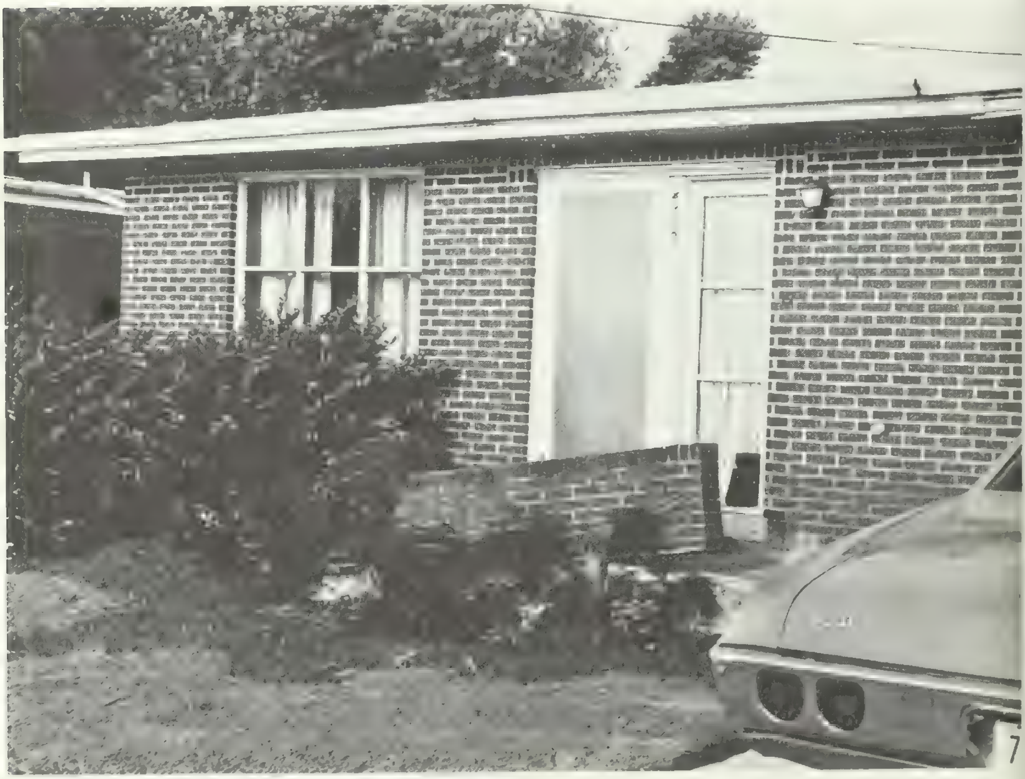


Figure 11.—Residence at 4309 Williams Boulevard, Kenner, with advanced tilting and cracking of low brick wall.



$600. One house experienced settlement of more than 11 inches (27.9 cm) in a 6-month span owing to a water-table change after adjacent construction. Shoring repairs on this property were estimated at $5,000, while other owners have paid between $1,200 and $6,000 for such work. Despite hopes of appreciation of about 2 percent per year, some have experienced a depreciation of as much as 25 percent in less than a decade (*Earle 1975, Carrier 1975, Aquanotes 1975*). In both the Village Del'Est and Harold Park subdivisions, the plethora of FOR SALE signs, added to the variety of other visual cues, is a further indication of consumer dissatisfaction with these problematic areas.

SUMMARY

The New Orleans esthetic landscape is the product of a melange of disparate influences, among which street-pattern orientation, drainage network, and especially topographic fluctuations resulting from land subsidence are most striking visually. While some districts provide more extreme and obvious cases of physical-esthetic interactions, these influences are nevertheless general throughout the entire urbanized region. Except for the most blatant and severe sorts of disruption, New Orleans residents seem to have implicitly accepted the gradual but perceptible change in form of their shared plot of ground as yet another part of the local ambience. The man-induced transformation of the New Orleans landscape has modified physical processes that are changing the surface configuration of the ground. This dynamic, almost fluid, nature of the land base is one of the paramount determinants of those visual qualities that constitute the New Orleans esthetic environment.

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Visual and Functional Components of the Built Environment: A Case Study of Urban Residential Neighborhoods

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ABSTRACT.—The hypothesis that visual and functional characteristics of neighborhoods influence the psychological well-being of residents was tested. An informal test by a survey of advertising strategies for selling real estate was first used. Second, data from a variety of published sources were used to identify some of the underlying dimensions of residential neighborhoods. The dimensions were used as independent variables to predict three different measures of psychological well-being in former mental patients. The results partially supported the hypothesized relationship by demonstrating that neighborhood type appeared to influence the patients' recuperation.

MY CONCERN IS the relationship between physical setting and human well-being in residential neighborhoods. It will be argued that an individual's neighborhood has a significant influence, both visually and functionally, on his or her psychological well-being. Background for these assumptions has been assembled in a variety of sources *(Angrist 1974, Peterson 1967, Smith 1975)*, which have made important contributions to burgeoning disciplines such as behavioral geography and environmental psychology *(Proshansky et al. 1970, Downs and Stea 1973, Amadeo and Golledge 1975, Zube et al. 1975, Lang et al. 1974)*. To substantiate these assumptions, I will describe a study designed: (1) to characterize some of the underlying visual and functional dimensions of residential neighborhoods, and (2) to test for a relationship between those dimensions and the psychological well-being of the residents.

I attempted to investigate characteristics of residential neighborhoods by analyzing the sales strategies adopted by realtors. It is reasonable to assume that sellers of residential units describe to potential customers the benefits they will realize if they choose to live in a particular neighborhood. We can also assume that the buyers expect to realize at least some of these benefits.

RESIDENTIAL NEIGHBORHOOD AND PSYCHOLOGICAL WELL-BEING

A city exists primarily to concentrate services for a large population in a relatively small area, and one of the most important of these services is providing people with a place to live. The residential unit and its adjacent neighborhood invariably become the spatial domain of the modern western person. Most of us spend at least two-thirds of our lives in and around the home, and some spend considerably more. Thus, although the neighborhood provides shelter, it may do much more; in fact the neighborhood can make us feel good or bad in varying degrees. A neighborhood may be pleasant to look at, it may be a happy place, and it may have a strong sense of community. On the other hand it may be ugly, anonymous, or sad.

It is convenient to class neighborhood characteristics into visual and functional components. Thus a neighborhood is first something we look at; and when we look, we may see features which please or displease us. We tend to look for trees, or hills and streams;

but often we see only factories, parking lots, and cars. At the same time, we interact with our neighborhood in other nonvisual ways. We live in a certain spatial unit, we move around in it, socialize in it, and breathe its air. Obviously the physical layout of the neighborhood, the amount of vehicular traffic, and its social composition, among other things, will influence the way we feel these interactions. In other words, the neighborhood may help or hinder our everyday functioning and the way we go about taking care of our needs.

Robert Sommer *(1974)* has recently developed this argument, at a more general level, in a book titled "Tight Spaces". Sommer described two distinct types of physical settings, one which is "hard" and unresponsive to human needs; and another which is "soft" and more likely to "welcome and reflect the presence of human beings."

VISUAL AND FUNCTIONAL COMPONENTS OF NEIGHBORHOOD: SOME IDEALIZED STATEMENTS

When a real-estate agent advertises a property, he tries to enhance the good points and minimize the not-so-good. Much of his selling strategy is concentrated on the residential unit, but often the neighborhood characteristics are included. In these cases, the information provided may be spatially bounded, to describe, for example, the view from the kitchen window. In other cases the information is aspatial in nature, for example, to describe the security or the type of neighbors one might expect to find. The information varies with the type of unit being sold, the income and age group of the prospective buyers, and the location of the property.

Nevertheless, by looking at the descriptions used in advertising residential property, we can get some indication of the ways the realtors expect the property to enhance the quality of an individual's life. Although the descriptions represent an idealized picture, as is the case in most advertising, we must assume they are based on some elements of truth, embellished in varying degrees by subjective evaluations.

Method

The Sunday newspapers of nine cities in the United States were analyzed for 4 consecutive weeks. They included a range of sizes and locations: New York, Los Angeles, Detroit, Dallas, Atlanta, Tulsa, Oklahoma City, Ann Arbor, and Norman. All advertisements in the real-estate pages were subjected to a content analysis, but only statements pertaining to the neighborhood were considered. No attempts were made to define "neighborhood" specifically, but it became apparent that any information that did not relate specifically to the residential unit or the apartment complex, should be considered.

In general, the search was for the adjectives and phrases used to describe the area in which the units were located. From the content analysis, a list of descriptive neighborhood features was generated, and a small sample of them is reproduced in table 1. It was evident that the descriptions were related to a variety of needs and desires that would appeal to the potential buyer, and some of these are suggested.

To organize the list of features and their related needs, the information was categorized heirarchically along the lines suggested by Abraham Maslow *(1968)*. Obviously it was not possible to defend rigorously the categorization shown in table 1, and there is no hard evidence to link the items with any of Maslow's needs. Similarly, each of the described features could be related to the satisfaction of more than one type of need. The table was constructed solely as a mnenomic device, and as a way to make some sense out of an extremely diverse set of needs and desires.

In selling a neighborhood, we can assume that the realtor believes, and would like the buyer to believe, that

Table 1.—Selling neighborhoods according to human needs*

Examples of neighborhood descriptions in advertisements	Related needs and desires	Maslow's needs
1. "Finest shopping close to Detroit" "Competitive rents" "Only 42 minutes from New York City via New Jersey Turnpike" "Save a fistful" "On a clear day you can see Big Boy"	Economy, accessibility, spaciousness, recreation convenience	Physiological
2. "Fox Briar Estates is trees, trees, trees . . . is Edmond Schools . . ." "Great place to bring up the kids" "Safe streets, safe neighborhood" "To keep you from turning green a 24-hour security patrol and staffed gatehouse"	Security, safe for children, privacy	Safety
3. "A unique community, friendly neighbors" "Creeks and wooded cliffs" "Rambling stone walls and open meadows . . . Canadian Geese and clear skies" "Rustic elegance . . . On a Sunday afternoon you see more horses than cars"	Sense of community neighborliness, friendship, trust, close to nature, esthetics	Love and belongin (natural and hum
4. "Prestige living in the fashionable sixties" (New York City) "We only look expensive" "Quality . . . and then some" "Dream neighborhood . . . luxurious"	Luxury, quality status, elegance, excitement	Esteem
5. "Live in a real townhome community, in town . . . in Dallas' prestigious eclectic neighborhood" "Avoid houses built in patterned conformity" "The best of everything" "Where you would like to spend the rest of your life"	Individuality, distinctiveness	Self actualization

*Needs are categorized according to Maslow's heirarchy (see text). No attempt is made to justif categories—they serve only as an illustration of the types of needs neighborhood characteristics n be related to. Many of the descriptions could be related to more than one need category. particularly difficult to relate statements to the higher levels of need: esteem and self-actualization

living in a certain neighborhood will be beneficial in a number of ways. To substantiate his claim, he appeals to some of the needs that might be satisfied if the buyer chooses to live in his property (table 1). Thus, he actively sells the neighborhood even though he may only own one or two of the residential units.

The appeal to different types of needs was recently investigated in another study in which a number of real-estate agents were asked to describe the sales tactics they would normally use in selling two identical houses in different parts of the city. The results of the study indicated that sales tactics are based, at least in part, on a subjective evaluation of how the neighborhood will cater to the needs of the potential buyer. It was interesting to note that significantly different strategies were adopted for selling urban fringe properties compared to within-city properties, a result that suggests that buyers on the urban fringe expect their house and neighborhood to cater to different types of needs and also that sellers are able to perceive such differences in needs.

From the investigations made thus far, there is reason to believe that neighborhood is bought and sold on the basis of its contribution to the need-satisfaction of the potential residents When we buy a property, we also get a piece of a neighborhood. We expect to like living in the neighborhood and we hope to benefit from it.

Residential neighborhoods can potentially cater to needs at many different levels. Some neighborhoods may satisfy only what Maslow called "low" leve needs such as safety and security, whereas others may also offer "higher" level need satisfaction, such as an esthetically pleasing environment and the opportunity to enhance one's individuality.

Theoretically at least, a neighborhood catering to a wide range of needs, particularly those "higher" on Maslow's heirarchy, would provide a more therapeutic and humane living environment. Unfortunately, to test such a hypothesis it would be necessary to find out whether the neighborhoods live up to the buyer's or the seller's expectations. In many cases we would find that the seller exaggerated the benefits and the buyer underestimated the shortcomings. Thus a real-estate agent might describe some neighborhood features very favorably. For example, a subdivision outside Ann Arbor might be described as ". . . a paradise somewhere west of Detroit"; and an apartment complex in Norman might feature ". . . beautiful lots—surrounded by large trees and rolling hills . . ." It is interesting how one can characterize the stunted black oaks and the flat plains of central Oklahoma! Realtors are usually skillful at turning something unpleasant into something hat at least sounds tolerable. An apartnent complex in Dallas, for example, at he intersection of two interstate highvays, can be described as ". . . convenintly located with four-lane access in very direction . . ."

The buyer may find that the adverisements were illusions; that the neighors are not so friendly after all; and hat the view is not nearly so nice when he sun isn't shining. For reasons such s these, neighborhood selling tactics re, at best, only an approximation of he actual benefits one might find from ving in a particular location. Neverneless, they provide an informal guidene and some insight into the types of sual and functional attributes of resintial neighborhoods.

VISUAL AND FUNCTIONAL COMPONENTS OF NEIGHBORHOOD: AN OBJECTIVE STUDY

Data were collected from a variety of sources to describe the visual and functional characteristics of a sample ($n = 102$) of residential neighborhoods in southeastern Michigan. It is important to point out at the outset that the visual and functional characteristics are not always entirely independent. For example, a high incidence of vehicular traffic would inhibit human functioning by preventing interaction and creating noise pollution, but at the same time the traffic would present a visual stimulus. In general, the variables were selected to describe visual and functional characteristics; in other words, they were chosen to describe (1) what could be seen in and around the neighborhood, and (2) any other features that might be related to human functioning and the satisfaction of needs in the neighborhood.

With an individual street address in the center, two data cells were constructed to represent each neighborhood. The first unit was a square cell 1,200 feet on all sides, which was intended to be a visual neighborhood, an area adjacent to the individual house and visible from the house. The size of the cell was determined in a pilot study as an average estimate of the distance visible from any given house. A larger unit, measuring 3,600 feet, was constructed to represent a largely nonvisual, but within-walking distance neighborhood surrounding the immediate neighborhood on all sides. Using these two cells, it was possible to collect data describing neighborhood character at different scales. This would be an advantage if the immediate neighborhood were not entirely representative of its surroundings. The 55 variables collected were intended to represent some of the visual and functional neighborhood characteristics for an individual residing at the center of the two data cells.

The variables were then used to identify some of the underlying characteristics of the residential neighborhoods in the sample. Using a combination of multidimensional scaling techniques described elsewhere *(Smith 1974)*, I identified 10 dimensions and named and described each one (table 2). As far as possible nonconnotative names were selected for the dimensions.

It was hypothesized that the dimensions describe at least some of the characteristics that would make a neighborhood more or less pleasant or stressful as a place to live in. To test such a hypothesis, it would be necessary to investigate a sample of individuals living in different residential neighborhoods. For every individual, scores could be assigned for each of the 10 dimensions; and those scores could subsequently be used as independent variables to predict psychological well-being

Method

As a first step in testing this hypothesis, the dimensions have been used t investigate the effects of the residentia environment on the psychological wellbeing of a group (n=71) of forme mental patients discharged from hospitals. From the medical records an from questionnaires, it was possible t construct three surrogate measures o well-being for the former patients:

1. *Recidivism/nonrecidivism.* — Thei ability to stay out of the hospital fo a period of 12 months.
2. *Good adjustment/poor adjustment* —From a follow-up questionnair completed 3 months after release,

Table 2.—The dimensions of residential neighborhoods

Dimension names	Items
Commercial/Industrial	Percentage of nonresidential structures
	Percentage of commercial/industrial land use
	Percentage of transportational land use
Recreational	Percentage of designated recreation
	Distance to nearest recreational facility
	Percentage of open space
Close to water	Distance to nearest water
	Percentage of cell covered by water
Arboreal	Hilliness—number of contours
	Percentage tree cover (individual trees)
	Percentage tree cover (in stands)
Low housing density	Distance between houses (side)
	Percentage of residential structures
	Space per house
	Percentage agricultural and vacant land
	Space per person
	Distance between houses (back)
	Distance between houses (front)
Black overcrowded	Percentage of black individuals
	Percentage of overcrowded units
	Percentage of female heads of household
Expensive real estate	Average unit value
	Average number of rooms per house
	Diversity of unit and street layout
Transience	Amount of through vehicular traffic
	Percentage of houses with boarders
Low unit density	Percentage of individuals over 65 years old
	Persons per unit
	Percentage of one-person units
Single-family uniform housing	Variety of residential building sizes
	Percentage of houses owned
	Variety of residential unit types
	Percentage of individuals
	Percentage of predominant land use
	Number of different land uses

composite measure of adjustment was constructed from items describing the interpersonal, social and recreational, family, employment, and community adjustment of the former patients. The mean score on this measure was used as a cut-off point.

3. *Low stress/high stress.* — Again from the follow-up questionnaire, this item was measured from the incidence and seriousness of stressful events encountered by the patients in the first 3 months after release. In a separate study a scoring mechanism was devised to assign weights to reflect the stressful nature of the different events. Again the mean score for the whole sample was used as a cut-off point. The construction of the scales was discussed in detail in Smith *(1974)*.

For each patient a profile describing his or her residential neighborhood was developed by assigning a score on each of the 10 residential dimensions described earlier. The profile was used in a discriminant analysis model to predict recidivism, adjustment, and stress in the former patients.

Prediction of Recidivism/Nonrecidivism

Scores on 3 of the 10 dimensions, Commercial/Industrial, Low Unit Density, and Transience — predicted outcome correctly for 46 (65 percent) of the 71 patients in the sample (table 3).

Although the prediction of return to the hospital is not remarkable, the results indicated that the type of neighborhood predicts correctly in nearly two out of every three cases which patients will return to the hospital. This is an interesting and encouraging finding, especially when compared to the actual rate of recidivism in the sample, which was over 50 percent. The implication, which is made extremely cautiously and perhaps even a little flippantly at this stage, is that a geographer, with information only on where in the community the patients live, can predict outcome significantly more accurately than the hospital staff.

The patient's neighborhood predicts staying out of the hospital more accurately than returning (25:10 as opposed to 21:15). One can suggest cautiously from this finding that some patients are able to compensate for, or to ignore, the negative and stressful effects of living in an unpleasant neighborhood — for example one with high scores on the Commercial/Industrial dimension or the Transience dimension. On the other hand, the positive benefits of living in a more pleasant setting appear to be substantial. The implication that the pleasant is therapeutic but that the unpleasant can be inhibited or shutout is irresistible.

It is important to make some statement concerning the Low Unit Density

Table 3.—Residential dimensions selected to discriminate return/nonreturn to hospital

Dimension	Percent correct prediction	d^2*	f statistic	Significance
Commercial/Industrial	53.5	0.21	3.77	0.05
Low unit density	64.8	.46	3.97	.02
Transience	64.8	.65	3.71	.01

CLASSIFICATION OF RETURN/NONRETURN

	No return	*Return*	*Total*
Correct group	25	21	46
Incorrect group	10	15	25
Total	35	36	71
Correct classification	46/71=65% p>95%		

*Mahalonobis distance function—a measure of the amount of discrimination between the two groups (see *Smith 1974*).

dimension, which describes neighborhoods with a high proportion of old people and people who live alone. The discriminant model indicated, somewhat surprisingly, that the patients who lived in neighborhoods with high scores on this dimension are more likely to stay out of the hospital than patients who lived in other neighborhoods. A tentative conclusion from this finding is that loneliness and a lack of social contact are not related to recidivism and nonrecidivism in former mental patients. It is possible that neighborhoods of this type are very familiar to mental patients, and that they provide a low-key setting in which the community makes few normative demands.

Prediction of Good Adjustment/Poor Adjustment

Two dimensions — Low Housing Density and Recreational — were selected as discriminators of adjustment (table 4), but the discrimination was not significant at the 95 percent level. It is interesting to note, however, that neither of these dimensions was included as a predictor of recidivism, which indicates that adjustment and recidivism are fairly independent of one another. This finding seems, at first, a little surprising because one would expect patients who adjust poorly to return to the hospital, and vice versa. On the other hand, it may be that recidivism rates do not reflect actual adjustment in the community. Patients living with their families, for example, may live a very sheltered life. They may not be required to adjust to community life in the broadest sense, but they do not return to the hospital because their family provides the necessary support.

The Low Housing Density and Recreational dimensions predict good adjustment much more accurately than poor adjustment (20:7 as opposed to 22:22). This too would indicate that the characteristics of some neighborhoods offer a substantial positive benefit. In this case, the results suggest that spacious neighborhoods may offer more room for people to move around in, more privacy, more opportunities for recreation, and so on.

Prediction of Low Stress/High Stress

The prediction of scores on the Stress index was the highest of the three well-being measures, with four dimensions selected as significant predictors (table 5). Arboreal, Commercial/Industrial, Low Unit Density, and Transience, together predicted the stress scores accurately for 49 of the 71 patients (69 percent). Three of these dimensions are the same as those selected to predict recidivism, which indicates that stress and return to the hospital might be closely related (and conversely, low

Table 4.—Residential dimensions selected to discriminate good adjustment/poor adjustment*

Dimension	Percent correct prediction	d^2	f statistic	Significance
Low housing density	53.5	0.23	3.59	0.06
Recreational	59.2	.41	3.08	.05

CLASSIFICATION OF GOOD ADJUSTMENT/POOR ADJUSTMENT

	Good adjustment	*Poor adjustment*	*Total*
Correct group	20	22	42
Incorrect group	7	22	29
Total	27	44	71
Correct classification	$42/71 = 59.2\%$ $p < 95\%$		

*The mean score was used as a cut-off point; patients with scores below the mean = good adjusters and vice versa.

Table 5.—Residential dimensions selected to discriminate low stress/high stress

Dimension	Percent correct prediction	d^2	f statistic	Significance
Arboreal	59.2	0.21	3.04	0.08
Commercial/industrial	60.6	.48	3.50	.03
Low unit density	64.8	.68	3.25	.02
Transience	69.0	.86	3.02	.02

CLASSIFICATION OF LOW STRESS/HIGH STRESS

	Low stress	*High stress*	*Total*
Correct group	20	29	49
Incorrect group	9	13	22
Total	29	42	71

Correct classification = 49/71 = 69% $p > 95\%$

stress is related to nonreturn to the hospital). It is reasonable to assume that the people who encounter a large number of stressful events and are unable to cope with these events, will be the ones most likely to return to the hospital. The inclusion of the Arboreal dimension in the overall prediction suggests that there are some positive benefits accruing to patients who live in hilly neighborhoods with tree-lined streets. Again, only a positive influence of the Arboreal dimension was detected.

For all three well-being measures, the results indicated that neighborhood characteristics predict outcome significantly in a sample of former mental patients. Some tentative explanations were provided, but one should proceed with great caution in suggesting cause and effect relationships. In another study the author has shown that the predictions made by the residential dimensions were almost as accurate as those made from a series of social and psychological variables collected in the follow-up questionnaire. In this exoratory study we concluded that the hypothesis relating the visual and functional character of residential neighborhoods to the satisfaction of human needs and psychological well-being, has been partially supported.

In ongoing work I am attempting to provide further support for the hypothesis by testing it in a normal population group.

SUMMARY AND CONCLUSIONS

The characteristics of an individual's residential neighborhood could contribute positively or negatively to his or her psychological well-being. An investigation of the advertising used to sell houses and apartments indicated that neighborhood is bought and sold at least partly on the basis of its ability to enhance the quality of life of the potential resident. To test the hypothesis, an empirical investigation was conducted, using a sample of residential neighborhoods in southeastern Michigan. Data describing the visual and functional characteristics of the neighborhoods were collapsed into 10 underlying dimensions, using a variety of multidimensional scaling techniques. With the scores on the 10 residential dimensions as independent variables, psychological well-being was predicted for a group of mental patients recently released from a large state hospital. The results showed that several of the residential dimensions could predict significantly the patients' scores on three measures of psychological well-being: recidivism, adjustment, and stress level.

Although the results should be interpreted with great caution, they at least indicate that certain neighborhood characteristics may offer a setting that is pleasing, relatively stress-free, and conducive to recuperation in former mental patients. The results suggested that positive and pleasant characteristics provide a therapeutic environment, but in most cases unsightly and negative characteristics were shown to have only a weak influence. At this stage it is not clear to what extent these findings are applicable to a normal population group, but research in this area is being conducted. One should beware of putting too much emphasis on the findings, bearing in mind the particularly powerful arguments against making ecological inferences of this type. The results suggest certain trends in the data, but it may be unwise to go beyond the most exploratory statements.

On the other hand, this study is an encouraging start, and has moved in an intuitively satisfying direction. The results and the methodology described point to both the feasibility and the desirability of attempting to measure some of the humane dimensions in the physical world. It is to be hoped that in further studies researchers will be able to characterize more clearly those elements of the built environment that are related to the enhancement of psychological well-being and the quality of human life.

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Environmental Perceptions of Residents of a Multifunctional Building

by MICHAEL L. BERGER, *assistant professor, Fordham University, New York, N. Y.*

ABSTRACT.—A multifunctional building in which residents could live, work, and entertain themselves without contact with the surrounding external urban environment is the subject of this study. To what extent do inhabitants of this structure perceive their thermal and acoustical environments within the building to be different from or similar to that outside? To what degree are discrete climatic and sound zones perceived within the structure itself? What factors account for such perceptions? Answers to these questions were provided by an analysis of the responses by 246 residents of the John Hancock Center in Chicago to a mail questionnaire.

THE CONCEPT of a single physical structure serving a multitude of functions is not particularly new. Buildings have long existed that housed a combination of services. Any large city, for example, contains office buildings with stores on the street floor, residential structures built over shops, and hotels with both offices and stores.

These multipurpose buildings owe their existence, mostly to economic considerations. They have been developed in such a manner because it was politically and financially advantageous to do so. Usually, little attention was given to the physical needs or wants of the people who were to inhabit them.

Recently, however, we have begun to see the erection of buildings that are designed to take care of the residents' social as well as economic needs. These structures are intended to be self-contained in the sense that they provide all the services and facilities necessary to sustain life. One could live, work, and be entertained within a single building. Such structures have recently been con-tructed in Chicago, Minneapolis/St. Paul, and New York City.

A good example of a multipurpose building with potential for self-containment is the John Hancock Center in Chicago. Erected in 1969, this 100-story tructure contains 29 floors of office space, 48 floors of apartment condominiums, and 11 floors of restaurants, lounges, and other residential and recreational services. In theory, it would be possible for residents of this condominium to lead relatively modern lives within the Center without ever coming into contact with outside people or the natural and physical environment of Chicago.

With this in mind, a study was undertaken in May 1975 to determine: (1) the degree to which the inhabitants of 175 East Delaware Place Condominium (the residential portion of the John Hancock Center) actually treated the Center as a self-contained building; and (2) how their residence in it influenced their perceptions of the environment both within and outside the John Hancock Center.

PROCEDURES

The instrument used in the study was a questionnaire mailed to a random sample of the apartments within the condominium. Ten suites on each of the 48 residential floors were surveyed. Of the 480 questionnaires distributed, 246 were returned in time to be analyzed for this study. This represents approximately one-third of the occupants of the condominium in the spring of 1975.

The questionnaire contained 10 questions. The respondent was asked to circle one of four choices given as possible answers. Judging from the relatively high rate of response for such a mail survey, the total lack of critical comments, and the rarity of unanswered questions, it can be inferred that both the questions and the answer choices were clear and readily understandable.

The first four questions were designed to obtain background information pertinent to the projected statistical analyses. They determined in what floor grouping the resident lived, the directional exposure of the apartment, how frequently the subject left the building, and his or her occupation.

The other six questions sought to ascertain the degree to which residents perceived differences in the climatic and acoustical environments present within and outside the John Hancock Center. Residents were asked how often they noticed differences between the outside climate and that within the Center, and between one area of the building and another. Similar questions were asked regarding the acoustical environment. An attempt was also made to determine whether residents tried to alter the thermal environment within their apartments.

The resulting data were subjected to three types of statistical analyses: (1) arrangement according to response percentages; (2) cross-tabulations to observe the nature of the distribution, chi-square technique being applied where appropriate; and (3) Pearson correlation coefficients to ascertain the degree of relationship between paired variables.

FINDINGS

The arrangement of the data according to response percentages yielded the following pertinent results.

1. Ninety-three percent of the residents responding indicated that they left the building at least once a day; 4 percent went outside every other day; and 1 percent left only every third day.

2. Eighty-nine percent of those replying always or sometimes observed a difference between the climate outside and that within the Center. Ten percent rarely or never did.

3. Seventy-one percent of the residents responding observed acoustical differences between the area within the Center and that outside. Twenty-nine percent rarely or never noted such differences.

4. Sixty-three percent of those responding indicated that they rarely or never sensed differences in the Center's internal climate from one area to another. Thirty-seven percent sensed climatic differences sometimes or always.

5. Sixty-eight percent of the residents replying rarely or never noted acoustical differences from one area of the Center to another. Thirty-two percent sometimes or always did.

The data responsible for these percentages were subjected to further statistical analyses to ascertain possible explanations for the perceptions revealed. These analyses yielded the following results:

6. A relationship of 17.94 with 9 degrees of freedom existed between the number of times a respondent left the Center per day and the degree of his or her perception of differences between the outside thermal environment and that within the Center.

7. A correlation of 0.21 existed between residents who perceived differences between the climate within and outside the Center and those who were sensitive to climatic zones within the structure.

8. A correlation of 0.31 existed between residents who perceived differences between the climate within and outside the Center and those who perceived acoustical differences in the sam areas.

9. A correlation of 0.47 existed between residents who perceived differen

climatic zones within the Center and those who sensed different acoustical areas within the building.

10. A correlation of 0.42 existed between residents who perceived differences between the acoustical environments within and outside the Center and those who sensed similar differences for acoustical zones within the structure.

11. A correlation of 0.31 existed between residents who perceived different climatic zones within the Center and those who sensed differences in the acoustical environments within and outside the Center.

CONCLUSIONS

Several conclusions seem warranted by the findings cited above.

1. Those residents responding did not choose to treat the John Hancock Center as a self-contained building. This can be seen in the overwhelming number (93 percent) of people who feel the need to leave the structure at least once each day.

In addition, the occupational breakdown of those responding indicated jobs that could be performed within the Center. Eighty-one percent of those replying classified themselves as business persons or professionals, while 14 percent said that they were housewives. Thus self-containment was a practical possibility for 95 percent of the respondents.

The most obvious explanation why these residents refused to remain in the Center for long periods of time is its placement in downtown Chicago. Because of the economic and social diversity available on the outside, the city acts like a magnet drawing the Center's inhabitants outward. It is interesting to speculate on whether the residents would behave differently if the Center were located in a medium-size city or small town.

2. Those residents responding were acutely aware of differences between the climate within and outside the Center. Eighty-nine percent of those replying always or sometimes observed such differences. This result is obviously not surprising.

However, the fact that 10 percent of the respondents rarely or never noted such differences is important. The thermal environment of the Center is an artificial one. One would expect nearly total agreement that such climatic differences always existed. The fact that this is not the case is all the more remarkable in a city like Chicago, which has a wide range in temperatures throughout the year. However, the timing of the survey may have adversely affected the results. May is a relatively temperate month, requiring little if any modification (heat/air-conditioning) of the Center's internal climate.

Nevertheless, there does seem to be some indication here that for a significant minority of Center residents the artificial environment, or the natural one, is not perceived to the degree that would be expected. This is an area in which further research is necessary.

3. A large majority of the respondents perceived acoustical differences between the environment within and outside the Center. Promotional literature for the condominium apartments stress that even the lowest ones, those on the 45th floor, are above street noises. Thus, it is not surprising that 71 percent of those replying perceived such distinct sound environments.

Yet, the fact that 29 percent of the subjects rarely or never noted such differences is remarkable. It is hard to explain how nearly one-third of the population would fail to note differences in the sound-intensity level when leaving or entering the Center, especially with its artificially-created acoustical environment. One possible explanation for the disparity between this figure and that concerned with climatic perception is that the respondents' sensitivity to acoustical differences is less well developed than their thermosensitivity.

This does little, however, to explain the inability of significant numbers of residents to perceive environmental changes.

4. A majority of the respondents did not note significant differences in the Center's internal environment from one area to another. This was true for both climatic and acoustical perceptions. Sixty-three percent and 68 percent respectively of those responding indicated that they rarely or never sensed such zones.

This conclusion is interesting in that it is difficult to believe that identical thermal and sound environments exist in every apartment, in each of the halls leading to them, in the lobby areas, in the supermarket, etc. While it is possible that the climate and acoustics within the Center are *relatively* uniform, this seems an insufficient explanation for the proportionally low level of perception.

It seems more likely that the concepts of climatic and thermal zones within a building may be such new ones that many of the respondents were not conscious of them or could not recognize them for what they were. In this sense, their thermosensitivity was in need of heightening.

5. A significant determinant of the degree of environmental perception for residents of the John Hancock Center was the frequency of trips they took outside the building. The more often a resident left the building, the more likely he or she was to perceive climatic differences between the environments within and outside the building.

It would appear that one's thermosensitivity was heightened or lowered depending on how often one left the building. If this is generally true, one might postulate that a more self-contained structure would lead to a diminution of thermosensitivity on the part of the residents. This is a point that deserves further investigation.

6. Those respondents who perceived differences between the environment within the Center and that outside also tended to be the ones who noted different environmental zones within the building. This was true for both thermal and acoustical observations. A correlation of 0.21 existed for the former and 0.42 for the latter.

These results indicate that residents sensitive to climatic or acoustical differences maintain this perception regardless of the environment in which they find themselves. In other words, the artificial environment within the Center brought out responses similar to those engendered by the natural and man-made environment of Chicago, or vice versa.

Furthermore, it seems that residents of the Center are twice as likely to have such similar perceptions in the acoustical realm as in the thermal one. Why this disparity should exist is not immediately apparent. Possibly the soundproofing of the Center is more effective than the thermal controls. This, in turn, may tend to make the residents more aware of acoustical changes. However, such a conclusion must remain tentative, pending further descriptive and statistical research.

7. The respondents who perceived thermal differences were more likely to sense acoustical differences as well, and vice versa. Thus there existed a correlation of 0.31 between residents who noted climatic *and* sound differences between the outside environment and that within the Center. Similarly, a correlation of 0.47 was found between subjects sensing discrete thermal *and* acoustical zones within the structure.

Thus it seems that thermosensitivity and audiosensitivity tend to develop together when present to a significant degree.

Why there should be a higher correlation concerning the internal environment is difficult to explain. It may be that such observations require a greater degree of perceptiveness than sensing indoor/outdoor differences, and that when it is present it is more likely to manifest itself in all sensory areas.

This study was primarily exploratory in nature. Most of the conclusions are tentative, and they point up the need for further research in this field. In addition, the results reported were based on a general analysis of the data generated, rather than a cell-by-cell exploration. It is possible that the latter will provide additional insight into the reasons for the apparent inconsistencies noted in the conclusions above. In any case, this is an area of investigation that deserves greater attention, particularly in light of the increasing number of multifunctional buildings being constructed in the United States.

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Relocation within the Urban Environment

by DAVID R. DiMARTINO, *assistant professor of geography, The Ohio State University, Marion.*

ABSTRACT.—Analysis of motives indicates that minimal consideration is given to the physical environment when urban households select from among alternative residential locations. There is a greater awareness of, and response to the economic and social conditions of the residential environment among movers. When the motivations of highly-educated white-collar professionals are correlated with their household characteristics and residency experience, few variables discriminate at all between those who view the physical environment as an important motive for relocation, and those who do not. The physical environment is cited more frequently (and considered more important) during the relocation process by owners of residences, rather than renters.

INTRA-URBAN RESIDENTIAL MOBILITY, the relocation of residents within their urban environment, is a behavioral process. Movers undertake a relocation based upon the perceived needs of their households; relocations are made in order to achieve some goal, to acquire some amenity at the new residence, or to avoid disamenity at the former residence.

The mobility process operates through the appraisal of alternative residential locations by the mover; as such, the mobility process is an adaptive mechanism within the urban environment. The motivations for relocating, as expressed by the movers themselves, are the best indication of both the causes of mobility and the residents' perceptions of the urban environment.

The mobility motives of households questioned in this study yields a perception of the city as a *non*physical, socioeconomic environment. The physical environment of the city is cited far less frequently as a motive for relocating, than are other social and economic considerations. And such physical environmental motives are usually couched in avoidance terms; that is, households which cite a physical environmental motive for relocating tend to seek an escape from the urban environment. Thus, not only are alternative physical environments in the city not sought, they are not perceived to exist.

RESEARCH DESIGN

Previous studies of residential mobility suggest that the rate of mobility is greater among families whose heads-of-household are highly educated and employed within white-collar professions *(Rossi 1955, Simmons 1968)*. The faculty members at the State University of New York at Binghamton were selected for examination as a significantly mobile and relatively informed study group.

Faculty to be investigated were selected via a random-stratified sampling procedure. The faculty members' names were grouped by university rank, and a random sample of faculty names was selected from within each rank (using a random-number generating computer program). The random-stratified sampling insures the selection of a study group with varying incomes, ages, and household characteristics.

A personal interview was conducted with each of the faculty members sampled. Twelve percent of the faculty were interviewed; those interviewed were involved in a total of 100 residential relocations within the Triple Cities area (the Binghamton/Johnson City/

Endicott area). The data base of the study thus consisted of 100 separate moves.

The interviews solicited information concerning both the respondents' household characteristics and mobility motives for each of their moves within the Triple Cities area. The respondents were asked to explain their motives for selecting a new residential location (rather than for vacating their previous residence).

Having completely stated their mobility motives, the respondents were asked to rank their motives according to their order of importance; they were ranked as the primary, secondary, and tertiary motives for their moves. Frequency tables of the respondents' primary, secondary, tertiary, and total motives were constructed; the tables arrayed both the individual motives and groups of related motives.

The mobility motives were then scaled (individually and by groups) along a continuum of what might be described as more- to less-functional motivations (materialistic to esthetic). The motivations thus scaled were compared to the variations in the background variables such as age of head-of-household, size of household, etc. The comparison was made by using a simple nonparametric correlation technique — Cross-Tabulation (the BMDO8D program of the UCLA Biomedical Programs series).

CHARACTERISTICS OF THE SAMPLE AND THEIR RELOCATIONS

The study group consisted of a rela- vely mobile set of households. As ighly-educated white-collar profes- onals they exhibited a relatively high mobility. And as relatively young mar- ed households of small size they also xhibited a mobility potential greater an the average, because they were in relatively early stages of their life-cycles (Rossi 1955).

In addition, the sample households ere relatively recent arrivals to the Triple Cities. Although their previous rental and ownership experience was considerable, their experience within the Triple Cities area was far less substantial. Their knowledge of the Triple Cities' residential environment, therefore, may have been incomplete; and this fact may have contributed to additional relocations within the area.

Indicative of their relatively recent arrival to the Triple Cities area, twice as many of the households utilized *non*-personal information sources for relocating (such as newspapers and realtors) as did personal information sources (such as friends and colleagues). Marrieds were particularly more dependent upon nonpersonal information sources than were singles; although the dependence upon nonpersonal sources decreased with the age of the head-of-household.

The respondents' dependence upon nonpersonal information sources was far greater than that characteristic of the more general mover population *(Rossi 1955)*. Thus, many of the mover households undertook relocations based upon information obtained from others; they made residential decisions based upon a combination of both their own and others' perceptions of the urban environment.

The information search which preceeds a mobility decision necessitates a time lag for most moves; there is time devoted to contemplating a move and time spent in searching for a new residence. Both the contemplation time and search time of the respondents in this study varied from no lag time (for spontaneous moves) to a period of 6 months. These lag times are typical of the general mover population *(Rossi 1955)*.

The respondents were atypical of the general mover population in that their contemplation and search time *increased* with the number of relocations made. Contemplation and search time usually decrease with additional relocations, because of the improved knowledge a household commands of a particular urban environment with additional mobility experience.

A possible explanation for the reversal of this relationship is that a number of respondents were changing their housing tenure status (renters becoming purchasers) ; the tenure change would require a different set of information for decision-making, and there would be a greater time period needed to acquire that new information.

MOBILITY MOTIVES

The motives which prompt a household to relocate within a particular urban environment yield an understanding of the causes of residential mobility; they also render a portrayal of the movers' perceptions of the urban residential environment. Examination of the mobility motives cited by the respondents of this study suggests a lesser concern with and/or perception of the physical environment, and a greater concern with the socioeconomic environment of the city.

Considerable variation existed in the individual motives cited by respondents as their reason for selecting a new residence. Several motives, however, were cited quite frequently. The five most frequently cited motives encompassed two-thirds of the total reasons and three-quarters of the primary reasons for relocating (table 1).

The single most frequently cited motive was the availability of housing; that motive was cited most frequently as both a primary and overall reason for selecting a new residential location (table 1). Cost was also frequently expressed as a motive for site selection. And, when grouped together as a category of mobility motives (table 2), the combination of availability and cost (labeled "constraints") accounted for the largest single group of both primary and total mobility motives.

While frequently cited as mobility motives, housing availability and cost are actually constraints exerted upon a household's mobility potential, rather than active causal agents of mobility. A household, for example, feels compelled to rent or purchase a residence at a cost in line with its budgetary limits; it may, however, select among a range of housing alternatives at costs equal to or less than those limits. The cost of housing thus serves as a limitation upon the range of alternatives, rather than an actual motive for relocating.

The frequency with which availability and cost are cited as reasons for relocating says much about the respondents' perceptions of the urban environment. Their frequency of citation demonstrates the respondents' perception of an extremely constricted housing market — a scarcity of housing. That perceived scarcity is relative, however; the scarcity includes housing with charac-

Table 1.—Individual mobility motives most frequently cited [Expressed as a percentage of total motives]

Motives	Motive rankings			
	Primary	Secondary	Tertiary	Total
Availability	24 (1)*	11 (3)	16 (2)	17 (1)
Cost	15 (3)	12 (2)	6 (4)	11 (4)
Age (newness)	—	—	6 (4)	—
Interior space	19 (2)	15 (1)	13 (3)	16 (2)
School district	8 (5)	10 (4)		7 (5)
Nearness to work	9 (4)	12 (2)	20 (1)	13 (3)
Summed percentages	75	60	61	64

*Order of frequency of motives within each ranking.

Table 2.—Categories of mobility motives cited [Expressed as a percentage of total motives]

Motive categories	Motive rankings			
	Primary	Secondary	Tertiary	Total
Constraints	40 (1)*	24 (2)	23 (3)	29 (1)
Structural traits	27 (2)	26 (1)	24 (2)	27 (2)
Neighborhood traits	12 (3)	19 (4)	12 (4)	14 (4)
Locational traits	10 (5)	20 (3)	29 (1)	18 (3)
Physical environmental traits	11 (4)	11 (5)	12 (4)	12 (5)

*Order of frequency of motives within each ranking.

teristics deemed necessary by the respondents, rather than a scarcity of all housing. The exact nature of the scarce characteristics is, of course, unclear.

Citing availability as a motive for the selection of a new residential site may also suggest a relatively less complete information search and/or more limited action space. These possibilities are consistent with the relatively recent arrival of many respondents to the Triple Cities area.

Aside from the motives of availability and cost, the most frequently cited motives for new site selection were: internal space (number of rooms), nearness to work place, and school district of the residence (table 1). These motives do yield information concerning the nature and location of housing preferred by the respondents; the motives, however, do not delimit any specific type of location or any specifically preferred urban environment.

A complete range of variation in the internal space of residences can be found in most housing districts of a city. Likewise, school districts, though area-specific, are usually large enough to include an ample range of housing types and residential environments. And selecting a new location close to one's workplace enables the household to choose from a range of housing types and residential environments, by virtue of the variable direction of a residence from one's workplace.

The five most frequently cited mobility motives are, thus, of minimal assistance in determining household preferences for specific urban environments. They do demonstrate the perceived needs of households and their reasons for relocating. They also yield insights into the general preferences of households for certain socioeconomic residential environments (such as type of education available for their children). But these motives yield little information concerning the preferences of the respondents for specific residential environments, particularly regarding the physical urban environment.

PHYSICAL ENVIRONMENTAL MOBILITY MOTIVES

Physical environmental concerns are cited infrequently as the mobility motives of the respondents in this study. This suggests either a lack of concern with or a lack of perception of the physical urban environment and its variations.

The individual mobility motives demonstrated a variable, though minimal, concern with the urban physical environment. The physical environmental motives involved two basic concerns: the esthetics of a residence (expressed as preferences for a view, scenery or a wooded lot), and the preference for a *non*urban, rural location. The most frequently cited single physical environmental motive was the desire for a scenic location, but that motive amounted to only 5 percent of the primary mobility motives (table 3).

When mobility motives were grouped

Table 3.—Physical environmental motives for household relocations
[Expressed as a percentage of total motives]

Motives	Motive rankings			
	Primary	Secondary	Tertiary	Total
Rural preference	5	4	2	4
Scenery	4	4	4	4
Wooded	1	0	2	1
View	0	3	3	2
Esthetic	1	0	1	1
Summed percentages	11	11	12	12

into categories (table 2), the physical environmental motives appeared as the least frequently cited category of total motives — 12 percent — and as the second-last category of primary motives cited — 11 percent. Although including a very small percentage of total and primary mobility motives, the physical environmental category did compare favorably in frequency to other categories of motives; it was comparable to neighborhood traits and locational traits among the primary motives, and to neighborhood traits among the total motives.

The physical environmental characteristics of the urban environment are, therefore, the traits deemed least significant to the relocations of the respondents in this study. And those few physical environmental traits which are considered important concern primarily the esthetics of the residential site — a subjective concern, and a concern very much in vogue at the time of this study.

The only other physical environmental concern of significance to the respondents was the preference for a *non*urban, rural residential location. That preference suggests an either/or logic in their decision-making; it demonstrates the respondents' perception of a noxious urban environment *(Wolpert 1966)* and a noxious environment of unvarying physical attributes.

The minimal expression of physical environmental motives for relocating is surprising in two respects. The respondents of this study were afforded the opportunity to cite their secondary and tertiary mobility motives, as well as their primary concern for moving; in view of that opportunity, a greater expression of physical environmental motives was expected.

In addition, the Triple Cities area extends through a quite variable physical environment; it is a riverine environment which varies widely in its range of vegetal, physiographic, and atmospheric characteristics. The respondents were thus expected to voice their preferences for residential locations within that environment.

The substantial variation in the physical attributes of the urban environment within the Triple Cities is thus of little concern to the respondents' relocations. The respondents evidence no perception of the variations in elevation, slope, insolation, humidity, pollution levels, etc. that exist among the various residential districts of the Triple Cities area.

SUMMARY AND CONCLUSIONS

The results of this study indicate the desires and perceptions of highly-educated white-collar professionals as they relocate their residences within the urban environment. These households express a range of concerns related to their mobility.

Their greatest concern in relocating is with the state of the housing market; they express a very great concern with the availability (and cost) of housing. That dramatic concern with housing availability and cost may result from a disparity between their perceived needs and their budgetary limitations; they may see themselves as belonging within certain residential districts (by virtue of the socioeconomic status of their profession), but may be unable to afford residences within those districts (because of their recent arrival to their profession with attendent starting salaries). Thus, their concern over housing availability may suggest a self-imposed constraint as the result of their stereotypical perceptions.

The mobility motives of the respondents also demonstrate their primary concern (aside from availability and cost) with the new residence itself and additional concern with other residential characteristics of relatively limited spatial extent. While neighborhood traits are cited as motives for the selection of new residential sites, those traits involve the evaluation of primarily adjacent properties together with the school system available — both concerns of relatively limited spatial dimensions. And, while relative location is cited as another motive for relocating, that concern involves the reduction of distance and travel time from the home to other ocations — a concern intended to limit contacts away from the residential district. Thus there appears to be a decreasing importance attached to mobility motives as the spatial expression of hose concerns increases — a decreasing mportance from residence traits to neighborhood traits to concerns with ome larger urban district.

The physical environmental motives xpressed by the respondents of this tudy are also concerns of limited spatial xtent. Aside from the desire for *non*-rban residential locations, the physical nvironmental motives focus upon the sthetics of the residential site itself — he vegetal cover, the outward view, etc. And, while purchasers tend to mention site esthetics and rural preferences for relocating more than do renters, neither group of residents expresses a preference for the alternative physical environments existent with in the Triple Cities area.

These findings suggest a lack of concern with the physical environmental characteristics which vary across the Triple Cities area: variations in such things as pollution levels, insolation, physiography, etc. That lack of concern may reflect a sincere feeling that physical environmental characteristics are of secondary importance to the relocation process; socioeconomic characteristics may be considered of greater importance. Alternatively, the movers may not perceive the urban environment as physically variable; urban residents may view the urban physical environment as spatially homogeneous.

Whichever the case, the results are the same. The urban physical environment *is* spatially variable, and that variability *should* be of concern to urban residents. Pollution levels, flood hazards, and a multitude of other physical environmental conditions all vary with the location of a residence within its urban environment; an understanding of that fact is basic to the health and safety of urban residents.

The findings of this study, therefore, point out the need for a greater educational effort by environmentalists (and others) aimed at urban residents. Whether urban residents remain unaware of the physical variations in the urban environment, or whether they are aware but unconcerned, the knowledge of the importance of those variations must be delivered to them. The improved knowledge that now exists concerning the spatial variations existent within urban physical environments is useless unless that knowledge is lent to all those who reside within that environment.

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Residential Settings: Effects of Home and Neighborhood on the Quality of Life for Old People

by JOEY EDWARDH, *Department of Geography, Syracuse University, Syracuse, N. Y.*

ABSTRACT.—The author discusses the role of home and neighborhood in the lives of old people and explores the impact of the physical and social organization of these spaces on an old person's perception of his immediate environment and his subsequent activity patterns. Home and neighborhood reinforce an old person's sense of identity and mediate between the old person and the larger society. Information about the meaning of home and neighborhood in the lives of old people contributes to the data available to those making the decisions that affect the distribution of social and physical resources in our cities.

THE ROLES OF HOME and neighborhood in the lives of people 65 years or older were studied in two very different urban environments in Syracuse, New York. The two environments will be called *Inner City* and *Northside.* The discussion is based on 60 interviews of approximately 2 hours length and work throughout the past 2 years with an old-peoples' advocacy group.

PHYSICAL AND SOCIAL ORGANIZATION OF THE STUDY AREAS

The Inner-City study area, historic-lly a working-class neighborhood, is ocated close to the high-rent central usiness district, near the transportaion hub of Syracuse. The Inner City is eterogeneous in character, with bar-estaurants, a large number of garage nd collision-repair shops, and small orner grocery and variety stores (fig.). Many of the garage and collision epair shops are tucked away in the ackyards of old houses. In addition to he small corner grocery stores, two rge supermarkets are located at op-osite ends of the area. A number of nkempt lots scattered throughout the rea have become graveyards for recked cars and discarded appliances. arge industrial structures are located ose to a variety of housing — small workingmen's cottages, tenement buildings, large single-family homes converted to apartments or boarding houses, and a low-income housing project.

The Northside area is a residential area located on the periphery of the city close to suburban shopping centers. It is a homogeneous residential area characterized by small single-family frame homes surrounded by spacious yards meticulously manicured (fig. 2). The homes are located on quiet streets off two major urban arteries, which provide easy access to other sections of the city. In addition, there are two local shopping centers.

A demographic profile of the Inner City and Northside study areas is summarized below:

- The mean age (72 years) is the same in both areas.
- The ethnic character of the Northside is predominantly German, with a considerable number of Italian and Irish families. Within the Inner City the sample is ethnically more mixed, with no dominant ethnic group.
- Catholicism is the preponderant religion of those in the total sample.
- Most of those residing on the Northside live with their spouses. Most of those in the Inner City are widowed.

Figure 1.—Map of Inner City land use.

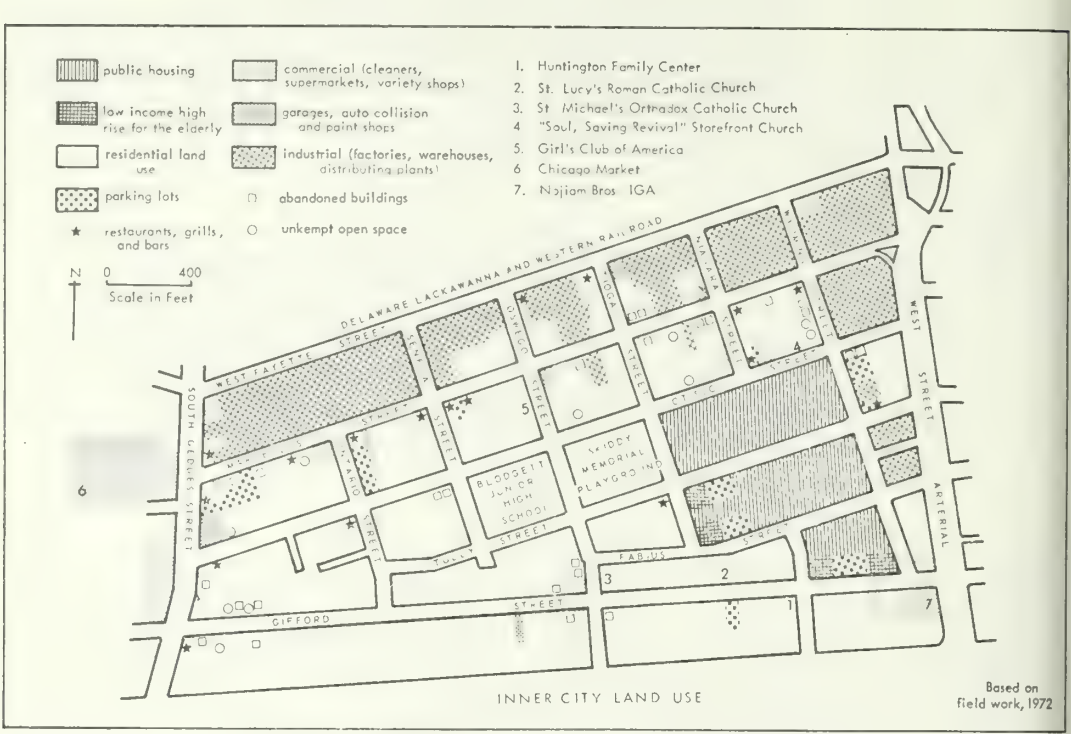
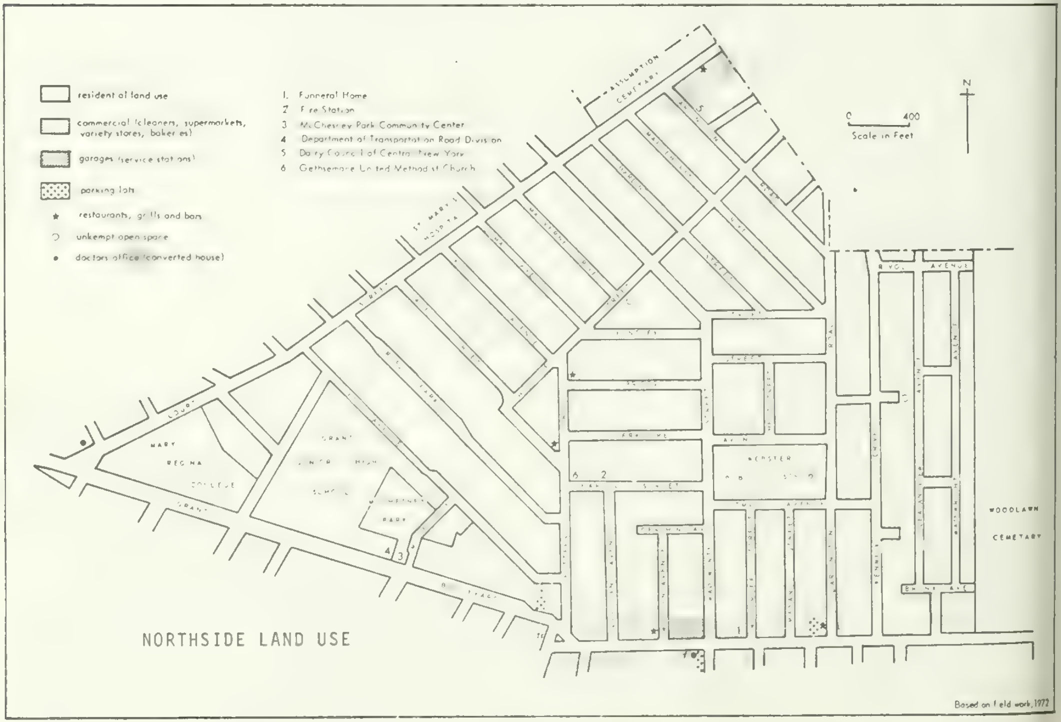

public housing
low income high rise for the elderly
residential land use
parking lots
restaurants, grills, and bars
commercial (cleaners, supermarkets, variety shops)
garages, auto collision and paint shops
industrial (factories, warehouses, distributing plants)
abandoned buildings
unkempt open space
1. Huntington Family Center
2. St. Lucy's Roman Catholic Church
3. St Michael's Orthodox Catholic Church
4 "Soul, Saving Revival" Storefront Church
5. Girl's Club of America
6 Chicago Market
7. Najiam Bros IGA
N
0 400
Scale in Feet
DELAWARE LACKAWANNA AND WESTERN RAILROAD
WEST FAYETTE STREET
SENECA STREET
OSWEGO STREET
TIOGA STREET
NIAGARA STREET
WEST STREET
SOUTH GEDDES STREET
ONTARIO STREET
CIVIC STREET
BLODGETT JUNIOR HIGH SCHOOL
SKIDDY MEMORIAL PLAYGROUND
TULLY STREET
FABIUS STREET
GIFFORD STREET
WEST STREET ARTERIAL
INNER CITY LAND USE
Based on field work, 1972

Figure 2.—Map of Northside land use.


resident al land use
commercial (cleaners, supermarkets, variety stores, bakeries)
garages (service stations)
parking lots
restaurants, grills and bars
unkempt open space
doctors office (converted house)
1. Funeral Home
2 Fire Station
3 McChesney Park Community Center
4 Department of Transportation Road Division
5 Dairy Council of Central New York
6 Gethsemane United Methodist Church
N
0 400
Scale in Feet
ASSUMPTION CEMETARY
ST MARY'S HOSPITAL
MARY REGINA COLLEGE
GRANT JUNIOR HIGH SCHOOL
WEBSTER
WOODLAWN CEMETARY
NORTHSIDE LAND USE
Based on field work, 1972

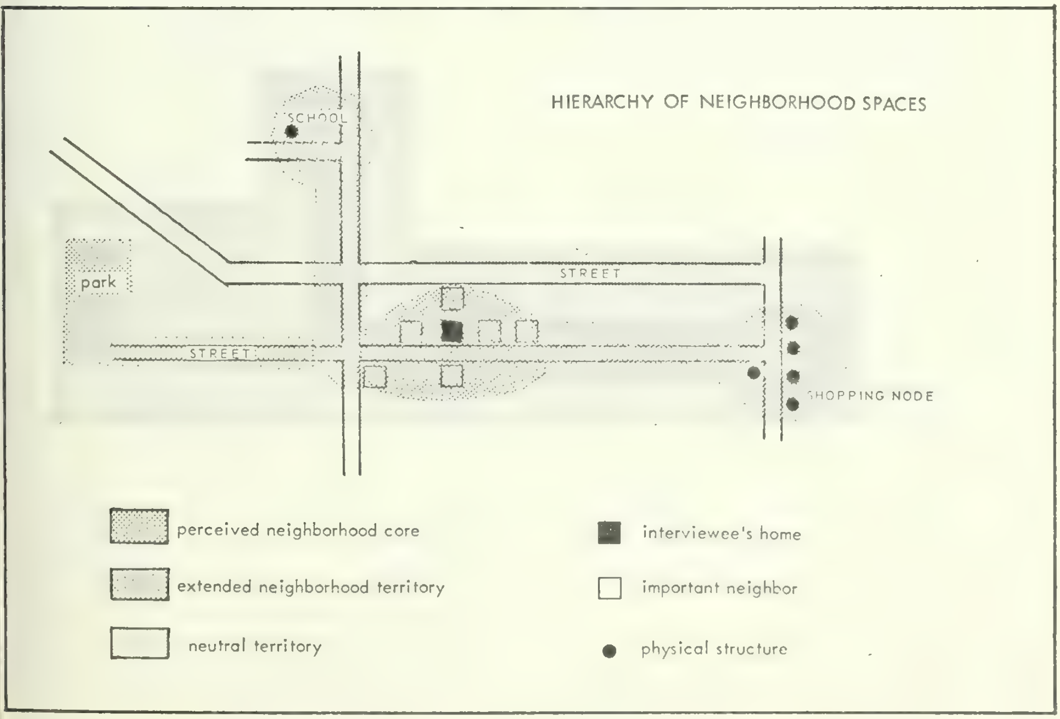
- Far more old people on the Northside have children than those living in the Inner City.
- More Inner City residents have physical disabilities.
- Years of schooling tend to be greater on the Northside, where approximately half of the residents have attended high school.
- Men in the sample population are retired blue collar workers. Most of the women in both areas who worked did so out of economic necessity.
- Residents of the two areas differed in financial status. Eighty percent of the Inner City elderly reported incomes below $3,000 as compared to 28 percent for the Northside. Most of those with incomes below $3,000 were single or widowed, and almost all of them were women. Most individuals in this income category have an annual income of approximately $1,500.

CONCEPTS OF NEIGHBORHOOD SPACE

The concept of neighborhood space is composed of two inherent ideas: proximate physical space and prescribed social interaction. An impression of the meaning of neighborhood to older respondents emerged from my interviews, the informal discussion, and field observations. The elderly perceived their neighborhood in terms of a hierarchy of spaces: home space, neighborhood core, extended neighborhood territory, and neutral territory on the periphery of the neighborhood (fig. 3). The concept of neighborhood is idiosyncratic in that each person has a different perception of his neighborhood space. Most often neighborhood space is perceived as both face sides of an average city block. Social communication and interaction occur in the neighborhood core that is close to the home.

In single-family residential sections

Figure 3.—Hierarchy of neighborhood spaces.



such as the Northside, the neighborhood core incorporates the people living next door, those directly across the street, and perhaps a few residing several houses away on the same street. Where fences and trees do not inhibit interaction with neighbors on the border of one's own backyard, this backyard territory is perceived as part of the neighborhood core. Services such as schools that the elderly's children attended, churches, small grocery stores, restaurants, and variety shops are encompassed in the extended neighborhood territory. The older person reaches these facilities by traversing a path from his home space through familiar and friendly territory to his place of destination. The elderly individual may stroll with confidence and ease both through his extended neighborhood territory and the neutral territory on the periphery of his neighborhood.

Similar concepts describe neighborhood space in the Inner City. Here factories, warehouses, parking lots, and public housing are interspersed throughout the environment. Usually these structures are not considered a part of an individual's neighborhood. For example, a number of individuals excluded from their perception of neighborhood those factories located across the street from their homes.

The presence of age-segregated highrise housing in the Inner City makes analysis of this area complex. The elderly in public housing tend to define their neighborhood in terms of their building. Their home space is the apartment, and their neighborhood core consists mainly of those apartments on the same floor and the common lounge. An elderly woman suggested that the building is a complete spatially contained environment where the elderly "are well taken care of . . . in the building we have everything."

The interviews suggested a number of reasons for this definition. Many of those in the public housing were new to the area and were uncomfortable outside the building. Age-segregated housing provides a multiplicity of services from laundry machines, Wednesday night bingo, to across-the-hall neighbors. This has made interaction with the neighborhood outside the building unnecessary. In addition, a number of those in the housing have poor health and were classified as severely restricted or housebound. Their limited mobility prescribes that their domain of interaction be inside the building.

HOME SPACE

Home space is an individual's personal territory. It is a bounded space, a place of privacy, a place to be oneself, a place where an individual can imprint his life experience and regulate his social interaction. It is that place where memory, special objects, and loved ones are physically or at least psychologically near.

Older people on the Northside were proud of their homes and wished to remain in them. The family throughout time embellishes the home with photographs, handicrafts, and other meaningful objects. Having a place where one's children and grandchildren can return provides some incentive to continue residing in the family home. Seventy-seven percent of the Northside respondents were satisfied with the present design of their home space. The only criticism articulated was a desire that everything be located on one level. As a person gets older, it becomes more difficult to climb up or down stairs. Although some believed that their home is too large for their current needs, others have used this space for their hobbies.

Work in gardens keeps older people outside and occupies much of their leisure time. Gardening also has a social dimension. While working in their gardens, people see their neighbors and can converse with them without being obligated to entertain them.

Only 21 percent of the Inner City respondents own their homes. Comments from this group suggested that they value their home space — the privacy, the garden — in the same manner as those on the Northside. However, notably absent from their remarks is the desire to maintain the home to accommodate family visits. An interview with a widow who lives alone illustrated the complexity of home ownership and home space in the Inner City. She had just sold her home, a large structure the front half of which is a vacant store front. This structure is a remnant of past days, where she, together with her now deceased husband, operated a small variety store. Her meticulously cared for apartment is in the back of the building. She talks freely about her reasons for selling and her present apprehensions. Her annual income of $2,500 left little money for taxes and the cost of house maintenance. Moreover, she describes her physical condition as "unsteady . . . I seem to want to do nothing . . . I have to expect this because of old age . . . it's hard for me to understand for I used to work so hard . . . I had such ambition." She stated her fears: "I dread looking for a new apartment . . . here is so near the drugstore and grocery store . . . I am afraid to move because I leave my memories . . ."

Her home, along with that of many others, is an artifact that symbolizes the link between present and past time and experience. Although most respondents want to remain in their own homes as long as possible, there is a threshold when they can no longer meet the demands resulting from diminishing financial and physical resources. At this point, the older person must look for a new residence to transform into a home.

Though most (79 percent) of the Inner City elderly are renters, they take pride in maintaining and organizing their apartments to express their own personalities. Financial limitations have restricted their housing choice to the Inner City. Nonetheless the interviewees, both in the neighborhood and in the age-segregated housing, cherish the privacy offered by their own apartments or home space. Many of the Inner City residents mentioned the lack of an outside space to garden or sit out in and talk with their neighbors.

PERCEPTIONS OF NEIGHBORHOODS BY OLD RESIDENTS

On the Northside, the general consensus was that the neighborhood was ideal for senior citizens. It is conveniently located, and small stores are within easy walking distance. In addition, it is near a large suburban shopping center. The response of one elderly couple describes the sentiments of many Northside residents. It is a "good place to live, quiet and clean with large lawns for garden work that appeals to senior citizens."

In the Inner City, the sentiments expressed were, most often, the antithesis of those expressed on the Northside. When asked if this neighborhood was a good place for senior citizens to live, one elderly man's simple statement, "No, it's not good for old people . . . it is dirty, noisy, and dangerous," reflects the thoughts of many. While they may not like their neighborhood, the majority find it conveniently located with easy access to basic services such as drycleaning, grocery and variety stores, banks, and a post office.

A crucial component of the elderly's relationship to their neighborhood is their perception of their environment, which translates into both constraints and opportunities that influence the quality of their life. Forty-three percent of the Northside's interviewees and 83 percent of the Inner City's were afraid to leave their homes after dark. Regardless of area, single and widowed respondents were not at all inclined to be outside after dark.

Very often the residents of the Northside felt insecure about activities that removed them from their homes at night, although few could cite any actual incident that had occurred within their neighborhood. There were those on the Northside who perceived the situation as more dangerous. One widow had so internalized her fear that she does not "dare sit out on the porch at night . . . I bolt the attic door and basement door at night . . . I am all closed up tight and don't even look out." There is little doubt that the mass media have increased the awareness of the Northside elderly concerning their personal vulnerability to the point where they, particularly widows, have altered both their perception of their environment and their behavior patterns.

The unequivocal response of the Inner City elderly was simply expressed by the statement, "You don't dare go out at night." Regret about this constraint was accompanied by the concession that in this neighborhood "years ago it was never like this — people could walk anywhere." Many of the elderly, through their neighborhood acquaintanceship networks, know of individuals who have been the victim of robberies, muggings, and rape. The presence of personal violence in their experiential world, along with the mass media emphasis on violence, engender and maintain a level of fear that ultimately inhibits any interaction outside of the home after dark.

But mobility at night is not the only time caution is exercised. The elderly, particularly women, are very concerned about themselves as easy daytime targets for purse-snatchers. A few had decided not to carry a purse when going out. Data from the Syracuse Police Department illustrating the distribution of burglaries, robberies, and public intoxication arrests in Syracuse suggest that the fears of Inner City residents are well founded.

In the Inner City, competition with other groups for the use of spaces and paths has usually meant that the elderly have retreated. For example, the location of the public housing for the elderly next to public housing for low-income families places two different groups — white elderly and black children — in spatial proximity. Competition for the use of public spaces, in this case sidewalks, ensues. As one elderly man exclaimed, "You can't walk around here; and if you try, the next thing that happens, some kid knocks you over with his bike." He, along with many others, moves slowly with care and is unable to easily get out of the way of a rapidly approaching bicycle.

The situation is exacerbated by verbal abuse from children and teenagers. Old people are the victims of name-calling and other verbal insults. Moreover, fear that the verbal assault may culminate in a physical act inhibits many elderly from criticizing or chastising the youth. They are aware that others, particularly old people, have been the victims of malicious damage such as rocks being thrown through windows.

All the public housing residents appreciate the material comforts and security afforded by residence in the building. Neat, efficient apartments, a garbage incinerator chute on each floor, and laundry facilities in the basement were the most popular benefits lauded. While proudly showing her apartment, one woman exclaimed "There are no leaks or roaches here . . . I waited three years to get an apartment . . . where else could I go? Where could I get an apartment like this for sixty-five dollars a month . . . it has a bathroom, good heat, three clothes presses."

Everyone was aware they could not possibly purchase similar accommodations on the open housing market. Though none wished to leave the housing, occasionally residents expressed a desire to relocate to newly constructed housing in more familiar neighborhoods.

It is not to be construed from these comments that public housing is the best solution to the housing needs of older people. Quite to the contrary, the move to public housing was the only alternative for these elderly. Once in the housing, a new definition of self and a reconstitution of one's social world occurs. It is my impression that the older people were grateful to have decent housing at a cost of 25 percent of their monthly income. This housing was viewed by the old respondents as a municipal gift rather than a right.

However, there is a pervasive fear that clouds life in the public housing. Because many residents lacked information about their rights as tenants in public housing, they feared that future investigations into their personal finances might lead to an increase in rent or a termination of lease. People were worried about fluctuating income ceilings and their possible effect on them. Furthermore, they were cautious in their criticism of housing authority policies, as few knew what the repercussion might be. No one mentioned the existence of any mechanism for tenants to discuss their problems with the housing officials. As one woman concluded, "the housing authority don't care what we want."

Northside residents were more satisfied with the noise level and cleanliness and condition of sidewalks than were Inner City residents (table I).

Noise pollution means that those in the Inner City awake early in the morning to the noise of food processers dispatching their trucks. Throughout the day and night, traffic noise from horns, screeching tires, and big trucks is omnipresent, because streets in this area are principal routes for the dispersion of goods throughout the city. The local bars are social nodes for others during the night hours; but for the elderly, the noise and general rowdiness prevent sleep and increase insecurity.

Environmental cleanliness distinguishes the Northside. A major disadvantage of the Inner City's mixed land use was illustrated by one man's statement: "Papers blow into my yard from the magazine plant across the street, and by the time I pick them up the yard is covered again." For the elderly, the decline in cleanliness and corresponding visual blight is shown not only by unkempt yards, unpainted houses, junk cars, and appliances, but also by garbage and containers strewn along the sidewalks.

The elderly are one of the few groups in our automobile society that use and need sidewalks. On a pleasant day, sidewalks are the paths accommodating those walking for pleasure and exercise. Furthermore, the majority of the elderly use public transportation, and to do so must use sidewalks to get to a bus stop.

Table I.—Satisfaction with neighborhood environmental quality

Characteristics	Northside			Inner City			**
	n*	Satisfied		n	Satisfied		α
	No.	*No.*	*Pct.*	*No.*	*No.*	*Pct.*	
Clean air	30	19	63.3	30	18	60.0	0.60
Number of trees	30	23	76.7	30	20	66.7	.20
Open space	30	27	90.0	30	22	73.3	.20
Curb height	26	22	84.6	30	20	66.7	.40
Noise level	30	17	56.7	30	8	26.7	.05
Snow shoveled	29	9	31.0	30	10	31.3	.95
Cleanliness	30	27	90.0	30	16	53.5	.01
Bus stop location	30	26	86.7	30	21	70.0	.02
Sidewalk condition	28	14	50.0	30	7	23.3	.10

*Number of people responding to each question.

**The chi square coefficient is used to determine whether the difference between areas was statistically significant. The 0.05 level was used to determine statistical significance.

Consequently, when sidewalks are missing, uneven, and severly cracked, older people have difficulty.

On the Northside, the major source of dissatisfaction was the absence of sidewalks along many of blocks, which forces people to fend for themselves on the roads. On the other hand, complaints from residents of the Inner City focused on deteriorating sidewalks. A number of individuals, afraid they might fall, refused to go out walking.

Poor sidewalk maintenance is worse in the winter. Only one-third of the interviewees were satisfied with snow removal from sidewalks in their neighborhoods. Most felt that they had no safe place to walk and often found themselves remaining indoors until some of the snow melted. For many, the winter means long and lonely days stretching into lonelier nights. Most important, access to public transportation becomes difficult. The snow removed from the streets is piled on the street corners, where it freezes into huge icy mounds that people must crawl over to reach the bus.

The majority of interviewees in both areas were satisfied with the location of bus stops. However, those on the Northside were more satisfied than those in the Inner City. Research in each area indicated that bus stops are distributed with regularity throughout each area. The disparity in response might be explained partly by the concept of psychological distance. The greater vulnerability of the elderly in the Inner City engenders anxiety and alters an individual's perception of the distance to the bus stop.

In both areas, the respondents did not say that they should have a right to clean air, trees, and open space. The concept of a public right to basic physical amenities is subordinated to the American value that promotes the notion that access to these amenities is assured through private ownership. Those without sufficient resources to purchase access to these basic physical amenities must go without.

NEIGHBORING

Neighboring has been broadly defined "as any interaction with people defined as neighbors". Those interviewed had no difficulty distinguishing between neighbors and family or friends. While neighbors can become friends or family can be neighbors, the spatially controlled term neighbor is applied to anyone who shares an individual's immediate urban space. In both the Northside and Inner City, almost everyone chats informally with neighbors; however, few attend neighborhood meetings or go to dinner or a movie with a neighbor. A considerable number of Northside elderly chat over coffee in a neighbor's home, but few engage in this social activity in the Inner City. When asked if they generally know when their neighbors are home, 93 percent of those on the Northside said yes, compared to 37 percent in the Inner City. Most important, all Northside residents and 77 percent of the Inner City elderly feel that they could depend on their neighbors for help. During an emergency their neighbors would call a doctor, their children, an ambulance, or take them to a hospital. No one expects a neighbor to help care for them during an illness.

On the Northside, all entered the area as home owners, and it was understood that all should maintain their homes and yards to prevent depreciation in property values. Over the years, this commitment has worked to minimize hostilities due to proximity. The subtle consensus that a good neighbor is one who maintains his propery puts pressure on all neighbors to fulfill this unwritten obligation. A sense of belonging reinforces those who fulfill this concept of good neighbor.

This philosophy is complemented by courteous interaction where "neighbors keep track of one another . . . when you need them, they are there." Yet time changes these patterns. According to an old woman, most of the elderly on her block have died or moved to special facilities. Their homes have been purchased by younger families who "are less friendly so I stay to myself". Furthermore, Northside neighboring has a seasonal dimension. People see and chat with their neighbors more often during the summer months, which brings people outside into their gardens.

The character of the Inner City is different from that of the Northside. As a result, it is not surprising that there are different patterns of neighboring. The transience of a renter population and the morphology of this urban area discourage those aspects of neighboring engendered by familiarity such as chatting with a neighbor in his home, knowing if your neighbor is home, and feeling you can rely on your neighbor for help.

A number of processes were operating that had contributed to the breakdown of neighborliness and neighborhood discipline. Most of the elderly considered the neighborhood to be in a state of decline from its previous status as a prosperous working class area. An elderly widow mentioned that across the street she no longer "knows anyone because people move in and out and no one takes care of the property". "The neighborhood is becoming run down", according to one elderly gentleman, since not only were "houses deteriorating" but also "many places were closed down — small businesses come and go and companies located next to the area were closed". Other racial groups are locating in the area, particularly Blacks, Puerto Ricans, and native Americans. The influx of these new neighbors has created hostility and fear.

In many cases, neighboring in the Inner City is in the form of a service where those less able are helped to get to basic services such as grocery stores. Twenty-eight percent of the Inner City elderly are completely dependent on neighbors and friends for assistance during an illness. Neighbors perform tasks such as reading mail to the blind or doing laundry for someone ill. Occasionally, expenses are shared. For example, a gentleman wanted to read both Syracuse daily newspapers but could afford only one of them; so he purchases one, his neighbor the other, and they exchange them.

All of the elderly living in the age-segregated public housing said that they could depend on their neighbors for help. For those in public housing this sentiment engendered a sense of security — there was someone to help them if they needed it. If an individual does not come to pick up his mail or visit the common lounge, someone will eventually check up on him. Interaction with one's neighbors occurs at important nodes throughout the building, particularly at the mail boxes, floor incinerator chutes, and lounge, and on the benches outside the front door. It was explained that people usually did not interrupt individuals in their apartments since they may be resting or eating, or just want to be alone. However, there are some who resent the omnipresent gossip network and consequently have curtailed their participation in any activities within the building.

CONCLUSION

Home and neighborhood are important spaces to older people since they reinforce one's sense of identity and mediate between the old person and the larger society. Home and neighborhood also help create continuity and coherence within the self.

However, the ultimate condition of old people in our society has little to do with their immediate physical and social space. Old people are the victims of a socioeconomic system that has no place for them. They no longer participate in the work force and consequently are not rewarded with material benefits. They are beyond the arbitrarily defined working years and are thought to be of little economic value and, as a result, of little social value. A social mythology cultivating youthfulness and deploring aging allows Americans to ignore those who have contributed to the productivity of this nation throughout their working lives. Reduced to poverty, old people have no resources to explore opportunities and choose alternatives that woul facilitate their adjustment to old age. I is difficult for most to purchase th necessities of life such as adequate food clothing, shelter, health care, transportation, and recreation.

Behavorial Significance of Milieu: a Consideration of Two Downtown Settings

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ABSTRACT.—Behavior patterns in parks and plazas in downtown Syracuse, New York, are discussed. After an introduction of the spaces and their principal users, fundamental concepts borrowed from ecological psychology are defined. Then using these concepts, the behavioral significance of the environment is illustrated in a comparison of two case studies. The concepts employed here are shown to allow a discussion of the important effect of environment on behavior without producing deterministic distortions.

THE OBJECTIVES of this exploratory research were to investigate (1) who was using parks and plazas in downtown Syracuse, New York; (2) whether behavior patterns were discernible in these spaces; and (3) the ways in which physical and social factors influence these patterns.

We soon discovered that distinct user groups and behavior patterns could be identified, and our attention then became focused on the ways in which social and physical factors work together to shape these behavior patterns. In considering our preliminary results, we found that some fundamental concepts taken from Barker's theory of behavior settings *(Barker 1968)* provided a very useful framework for interpretation. After setting the context and defining these concepts, we will discuss two case studies that illustrate some of the mechanisms relating behavior patterns and physical environments.

THE CONTEXT

For two summers (1974 and 1975), outdoor amenity spaces in downtown Syracuse were studied. In many respects, Syracuse is a typical medium-size city (population, city limits: 157,000; Standard Metropolitan Statistical Area: 637,000). It is undergoing the same demographic and economic changes as most other American cities: residential movement to the suburbs is leaving a deteriorating central city and an ailing Central Business District (CBD). A keen interest in CBD amenity spaces is one expression of a campaign by city officials, businessmen, and assorted Syracuse enthusiasts to revitalize the downtown.

The set of outdoor amenity spaces investigated for this study included (fig. 1): (1) two commonly recognized loci of downtown social activity, Columbus Circle and Clinton Square; (2) one space dominated by urban drifters and derelicts, Hanover Square; (3) one space used primarily by retired men, Vanderbilt Square; (4) two spaces associated with large new offices buildings, MONY Plaza and Lincoln Center; and (5) two large but little used spaces, Everson Plaza and Fayette Park.

For this whole set of spaces, five major user groups can be identified in terms of their influence on daytime behavior patterns:

1. *Female office workers.* — This group consists mostly of single females

social value. A social mythology cultivating youthfulness and deploring aging allows Americans to ignore those who have contributed to the productivity of this nation throughout their working lives. Reduced to poverty, old people have no resources to explore opportunities and choose alternatives that would facilitate their adjustment to old age. It is difficult for most to purchase the necessities of life such as adequate food, clothing, shelter, health care, transportation, and recreation.

Behavorial Significance of Milieu: a Consideration of Two Downtown Settings

by DOUGLAS L. ROBERTSON *and* ROWAN A. ROWNTREE, *respectively doctoral candidate and associate professor, Department of Geography, Syracuse University, Syracuse, N. Y.* *This research was supported in part by funds provided by the USDA Forest Service, Northeastern Forest Experiment Station, through the Pinchot Institute for Environmental Forestry Research, Consortium for Environmental Forestry Studies.*

ABSTRACT.—Behavior patterns in parks and plazas in downtown Syracuse, New York, are discussed. After an introduction of the spaces and their principal users, fundamental concepts borrowed from ecological psychology are defined. Then using these concepts, the behavioral significance of the environment is illustrated in a comparison of two case studies. The concepts employed here are shown to allow a discussion of the important effect of environment on behavior without producing deterministic distortions.

THE OBJECTIVES of this exploratory research were to investigate (1) who was using parks and plazas in downtown Syracuse, New York; (2) whether behavior patterns were discernible in these spaces; and (3) the ways in which physical and social factors influence these patterns.

We soon discovered that distinct user groups and behavior patterns could be identified, and our attention then became focused on the ways in which social and physical factors work together to shape these behavior patterns. In considering our preliminary results, we found that some fundamental concepts taken from Barker's theory of behavior settings *(Barker 1968)* provided a very useful framework for interpretation. After setting the context and defining these concepts, we will discuss two case studies that illustrate some of the mechanisms relating behavior patterns and physical environments.

THE CONTEXT

For two summers (1974 and 1975), outdoor amenity spaces in downtown Syracuse were studied. In many respects, Syracuse is a typical medium-size city (population, city limits: 157,000; Standard Metropolitan Statistical Area: 637,000). It is undergoing the same demographic and economic changes as most other American cities: residential movement to the suburbs is leaving a deteriorating central city and an ailing Central Business District (CBD). A keen interest in CBD amenity spaces is one expression of a campaign by city officials, businessmen, and assorted Syracuse enthusiasts to revitalize the downtown.

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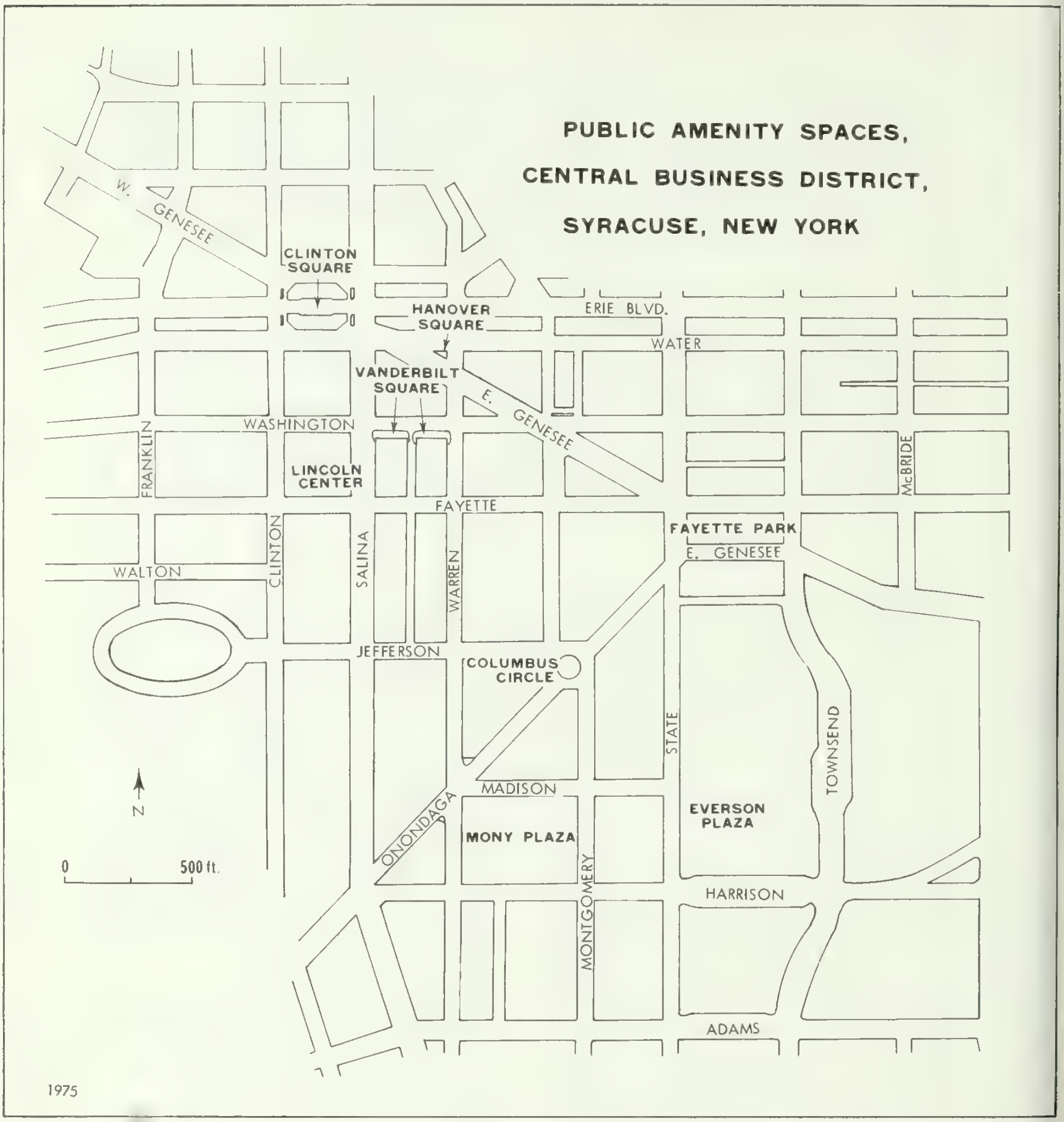
For this whole set of spaces, five major user groups can be identified in terms of their influence on daytime behavior patterns:

1. *Female office workers.* — This group consists mostly of single females

Figure 1.—Parks and plazas studied in downtown Syracuse.



between the ages of 18 and 30 engaged in clerical work downtown (secretaries, file clerks, key punch operators).

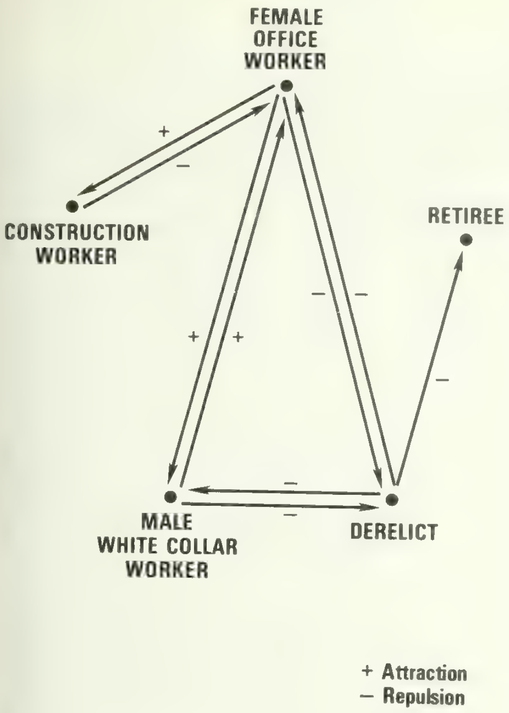
2. *Male white-collar workers.*—These men are mostly between the ages of 18 and 30 and are employed in sales, administration, and professional occupations.

3. *Construction workers.* — As the CBD undergoes physical transformation, these men are employed to demolish old structures and build new ones. Their labor is of both the unskilled and skilled varieties. In age range, they are similar to the male white-collar workers.

4. *Male retirees.* — These elderly men regularly venture downtown to meet with their cohorts for a day of reading and conversation.

5. *Derelicts.* — Mostly between the ages of 30 and 50, at least half of these men are obvious alcoholics. Many of them panhandle throughout the downtown, but use Hanover Square (for decades called "Hangover Square") as their home base.

Figure 2.—Relationships between user groups in downtown parks and plazas.



Interaction between these groups is important to the behavioral fabric of the downtown. Our observations suggest linkages of attraction and repulsion (fig. 2). It should be noted that these relationships are simple abstractions that refer to how two groups will interrelate in the absence of other groups. These basic relationships, however, can be altered under various circumstances such as the presence of other groups. For example, derelicts will be less threatening to female office workers when male white-collar workers are present.

BEHAVIOR SETTINGS

From Barker's ecological psychology, we have drawn a set of concepts that allows us to discuss the significance of environment to behavior without implying rigid deterministic causality. We have found these concepts very useful for our work in Syracuse and are convinced that they have value for other social scientists and designers interested in environment and behavior.

The grand concept of ecological psychology is the "behavior setting" *(Barker 1968:18-34)*. This is a behavioral unit that refers to an enduring pattern of behaviors situated in time and space. A university class meeting is a good example of a behavior setting: a variety of role interactions (professor, student, man, woman) produce an overall pattern of behavior that has a definite bounded location (a classroom) and a definite beginning and end (the class hour). It is important to recognize that a behavior setting is behavior, space, and time—all three as equal elements—in interrelationship.

The behavioral component of a behavior setting is called the "standing pattern of behavior". These are behavior patterns of people en masse, which are set in a particular time and place. For example, in downtown parks we found standing patterns of behavior that appeared and disappeared with the lunch hour. Individuals would enter and leave these patterns freely; yet the patterns would persist throughout the lunch hour, day to day, week to week. Standing patterns of behavior do not depend on the particular individuals involved.

The "milieu" is the "objective" component of a behavior setting. The spatial and temporal ambience of behavior, existing independently of anyone's perception of it, constitutes the milieu. The major features of the milieus we studied were the individual morphologies of the downtown amenity spaces and the hours between 11:30 a.m. and 1:30 p.m. on summer weekdays.

In a behavior setting, the behavior and milieu are said to be "synomorphic." This simply means that the behavior and its spatial and temporal ambience are somehow compatible. For example, one does not go to a downtown plaza to practice belly dancing; it hardly seems like the appropriate environment. We will explore some of the mechanisms involved in synomorphism in more detail later.

Behavior-milieu units are called "synomorphs." With this term, a much needed word is added to the vocabulary of the environmental designer and researcher. Synomorphs are not behavior alone, nor milieu alone; they are behavior, space, and time, all together in a single unit.

Behavior settings are *sets* of synomorphs. For example, the standing patterns of behavior *and* the space and time of downtown parks during summer weekday lunch hours are behavior settings. Some of these behavior settings comprise a single synomorph, while others, because of spatial divisions within the space, include several synomorphs.

For a variety of reasons, ecological psychology is certainly *not* the final word in behavioral research: much of Barker's work introduces a precision that obscures rather than illuminates. But, even so, we find that the concepts just defined allow a useful perspective for discussions of environment and behavior. The following case studies will serve to demonstrate.

CASE STUDIES

This discussion of the lunchtime behavior settings in Columbus Circle and Clinton Square illustrates some of the mechanisms — both social and physical — involved with synomorphism. For those interested in behavior — especially for designers — this is a vitally important issue since the significance of the relationship of behavior and its context is affirmed repeatedly. The designer must be sensitive to the mechanisms involved in synomorphism. His charge is to produce particular kinds of behavior settings, not simply to add artifacts to the landscape. The empirica record for this point has been neglecte by ecological psychologists, and we hope with these brief case studies, to begin t remedy this deficiency.

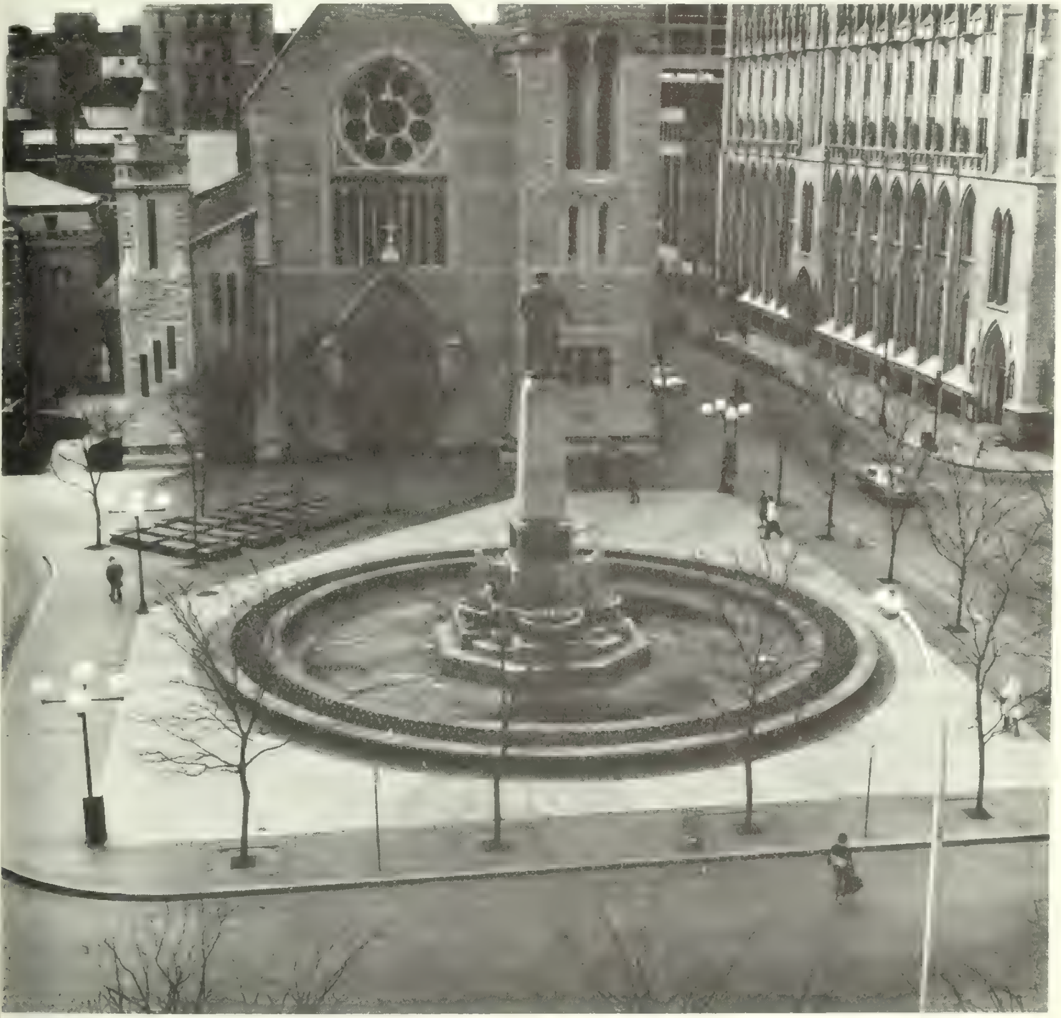
Columbus Circle and Clinton Square share many characteristics: they are the two most commonly recognized CBD parks; each has historical significance they are both large and centrally located; each is a major pedestrian intersection; all the major user groups have access to each space; each has a similarly large number of potential users; and both provide a pleasant esthetic experience. In spite of these similarities, however, the standing patterns of behavior for each setting are clearly different The festive behavior setting in Columbus Circle is in striking contrast to the subdued setting in Clinton Square. The milieu for each setting is also clearly different. Consistent with the principle of behavior-milieu synomorphism, behavioral differences can be largely understood by examining milieu differences.

Columbus Circle

Columbus Circle is a relatively large park located in the southern part of the CBD (fig. 1 and 3). It is snugly situated in the midst of mostly municipal and religious buildings: the Public Library to the north, the County Courthouse to the east, a Catholic cathedral to the west, and, on the south, a six-story office building. At one time a small traffic rotary, the western half of the Circle was recently connected to the front of the cathedral, and walking and sitting areas were developed around the fountain. Still a major pedestrian intersection, Columbus Circle is now the most heavily used park in the CBD; during the summer an average of about 80 people will congregate there at lunchtime.

Observation has shown that, in terms of the proportion of the total lunchtime user population, three groups dominate

Figure 3.—Columbus Circle, looking west. This photograph, taken in the spring, shows Columbus Circle still packed up for the winter; during the summer, benches are moved from the center of the cluster, and the fountain is in operation.



in Columbus Circle: female office workers, male white-collar workers, and construction workers. The standing pattern of behavior is heavily influenced by the nteraction of these three groups.

Several types of behavior are common n the standing pattern: people watching, sunning, socializing, "hanging out" (waiting for unarranged gatherings to materialize), and, of course, eating. Columbus Circle is a vibrant behavior setting during the lunch hour, with a great deal of interaction occurring both between and within participating user groups.

Perhaps the most common behavior in the pattern is people watching. On a typical day, a large majority of the Columbus Circle participants openly engage in this activity. The milieu of lunchtime Columbus Circle is particularly well suited for this behavior. With regard to the temporal aspects of the milieu, a summer weekday lunch hour is one of the times of peak pedestrian circulation in the CBD. This is obvious, and it is a milieu characteristic which is, of course, not unique to Columbus Circle.

More interesting is the way in which the morphology of Columbus Circle serves the activity of people watching. The relationship of paths (invisible pedestrian corridors) and seating areas (benches and ledges) in Columbus Circle is such that most seats offer the individual a view, from a comfortable distance, of several lanes of movement. Furthermore, the seating areas are arranged so that users may discreetly view one another. One seating area, the southern quadrant of the fountain ledge, stands out among the others and can be considered a "stage" (an area that is a visual center of attraction and is visually connected to seating or viewing areas). Those who sit on the stage know that they are being watched, and they either choose to "perform" (become consciously involved with that visual interaction) or choose to ignore it. For those who wish to ignore it, the masking sound of the fountain facilitates insulation. Visual variety is evident: people can easily watch others within the context of paths, seating areas, and a stage.

A specialized and popular type of people-watching at Columbus Circle is girl-watching. The arrangement of seating areas and the stage serves this behavior remarkably well. The stage is not only the most visually accessible to other seating areas, but it is also the optimal sunning area. On a clear summer day, female office workers take to the stage, with their chins uptilted toward the sun and their legs outstretched in an unmistakable sunning pose. Of course, some are less dramatic and simply sit normally postured and chat with friends. Whether or not they perform on the stage, their presence encourages the presence of other groups in nearby viewing areas — specifically male white-collar workers and construction workers.

When interviewed, both these groups were explicit about their interest in the young ladies. Also, their location in the bench cluster in the southwest section o the Circle — an optimal position fo viewing both the stage and paths — clearly demonstrates this interest.

The reaction of female office workers to construction workers is commonly negative: the earthy candor of the construction workers is not appreciated by the female office workers. In such proximity as just described, the constructio workers' comments on the scene woul perhaps be enough to convince the female office workers to move on. However, the sound of the fountain in the background is sufficient to remove the performers from their audience's verba indiscretions.

Socializing is also a common activity in the Columbus Circle behavior setting: small groups engage in conversation some individuals also moving freely among groups. The nature of the benches is such that six adults and thei lunches can be accommodated comfort ably on the same bench, and around th fountain ledge three adults can easily group together. Also, the visual an spatial proximity of seating areas make it convenient to move from one area t another. The physical characteristics o Columbus Circle are highly compatibl with gregarious socializing.

Related to people-watching and social izing is the activity of "hanging out" (waiting for spontaneous gatherings t occur). At least two features are re quired of a behavior setting so that i be appropriate for hanging out: first, i must serve as a popular gathering place and, second, easy viewing of the spac must be possible. As already discussed Columbus Circle satisfies both thes conditions.

Columbus Circle is, in short, "wher the action is." Individuals gather t partake of the physical amenities and t interact socially with each other in variety of ways. The milieu can be see to encourage these pursuits.

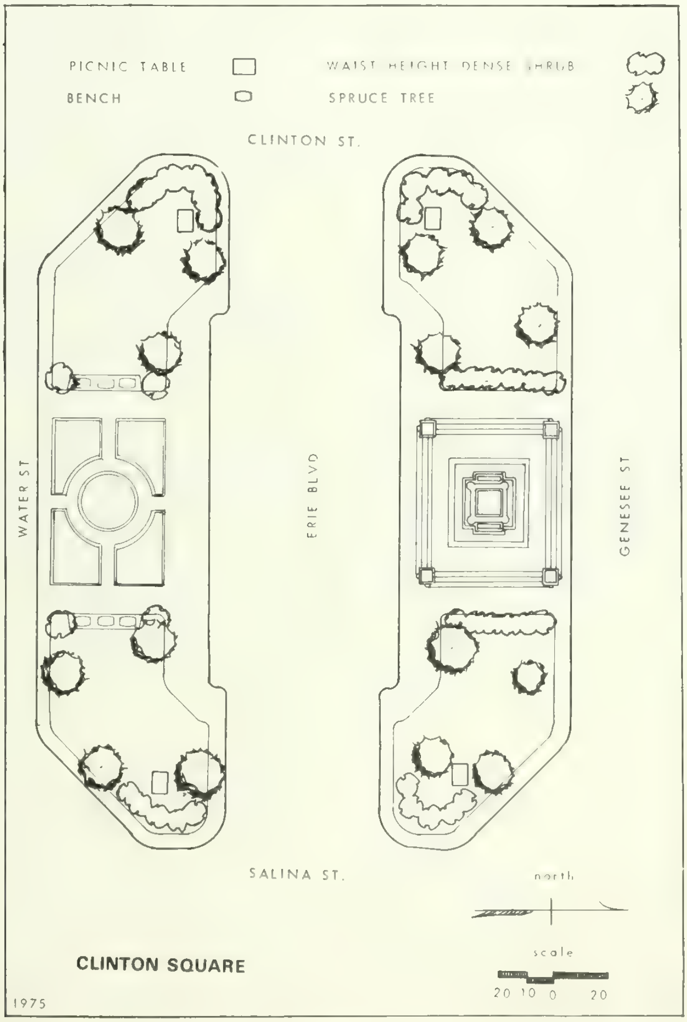
Clinton Square

Clinton Square is a spacious park situated in the northern part of the CBD at the intersection of two major four lane arteries (fig. 1 and 4). The space is bordered on three sides — north, east, and west — by busy streets and is bisected by a major boulevard. The park essentially comprises two large grassy, relatively peaceful islands protected by dense shrubs and spruce trees from enveloping currents of traffic.

Strictly speaking, Clinton Square is probably two behavior settings rather than one. The southern part, with its fountain, its relatively tranquil southern boundary, and its proximity to shopping, is easily the most popular. Our focus will be on this section.

Clinton Square is surrounded by municipal and commercial buildings; however, they are all separated from the Square by streets and parking lots. The buildings serve mainly as a backdrop to openness. Major employers are located nearby to the north and west of the Square. Because the principal lunchtime pedestrian flow is towards the main street on the park's eastern border, Clinton Square is a major pedestrian

Figure 4.—Clinton Square with its two parts, the fountain section to the south and the monument section to the north.



intersection at the noon hour. On the average, about 35 people use Clinton Square at lunchtime — slightly less than half the number using Columbus Circle.

Two user groups from the mainstay of the Clinton Square behavior setting: female office workers and construction workers. Interaction between the two groups plays little part in the character of the behavior setting.

Besides eating, only two types of behavior are common in the setting: socializing and "getting away" (any of a variety of solitary behaviors such as daydreaming, sleeping, and reading). The behavior setting is relatively quiet, and separate behaviors within the space are only tenuously integrated.

Socializing is the most commonly observed behavior in the setting. It is, however, a different variety than the type described in Columbus Circle. People come to Clinton Square in small groups, or they meet people there; they do not come to partake of a bustling social scene. Individuals are not seen visiting from group to group. Instead, private conversation and intimacy characterize the gatherings.

This type of low-key social scene can be better understood by examining the morphological aspects of Clinton Square's milieu. Intimate socializing is fostered by the compartmental structure and the limited seating of Clinton Square. The park is a series of seating areas separated by thick hedges, trees, and a fountain. The vegetation barriers provide both visual and acoustic insulation. Viewing lanes are generally not well developed, and it is impossible to scan the whole setting from any particular position.

Notice that despite the presence of female office workers, the highly compatible groups of male white-collar workers are not present. The barriers are so formidable that they restrict even the most aggressive girl-watchers — construction workers — to simple conversation among themselves. These characteristics not only make it difficult to feel a part of a large spontaneous social happening, but they also decrease the sense of protection characteristic of a highly integrated behavior setting. People can more easily feel vulnerable when separate from a large group. Also, the barriers make it difficult to assess possible threats present in the situation. These morphological restrictions on interaction and on situational legibility encourage many users to come to Clinton Square *with* their social companions rather than seek them in the space.

The other common behavior in the setting is "getting away". As just discussed, the morphology of Clinton Square provides ample privacy for any behavior from this set of solitary activities. Also, because of the morphology's effect on the nature of the socializing occurring in the behavior setting, solitary behavior blends well with the other common behavior. Getting away is not only physically possible but also socially consistent.

CONCLUSION

In comparing the lunchtime behavior settings at Columbus Circle and Clinton Square, we have seen the principle of behavior-milieu synomorphism in operation.

Each space has approximately the same contextual properties: easy access by all major user groups, a large number of potential participants, and proximity to restaurants and shops. Each space is a perceptual central place. Each space offers a similarly pleasant esthetic experience.

Yet, despite a host of similarities, two distinctly different behavior settings emerge from these spaces. We have seen that differences in behavior patterns can be directly linked to milieu differences. We have also specified some of the physical and social mechanisms by which this linkage occurs. Participants in these behavior settings respond to the physical pleasures of sun and attractive sights and sounds. They also engage or disengage in a variety of social interactions such as talking to, watching, being watched by, and avoiding other people. We have seen how people, as physical *and* social entities, respond to different milieus to create different standing patterns of behavior.

It is often a tricky exercise to discuss the genuine behavioral significance of the environment free from deterministic overtones. Part of the problem is an inadequate vocabulary. In our discussion of Columbus Circle and Clinton Square, we have demonstrated that some of the concepts of ecological psychology can solve that problem. Within Barker's conceptual framework, we discussed behavior which was *compatible* with the milieu rather than behavior which was the *product* of the milieu. We discussed enduring *standing patterns of behavior* rather than bogging down in simple behavior. We noted that standing patterns of behavior and milieu were compatible in behavior settings *without* depriving individuals, even large numbers of individuals, of the freedom to behave in ways that are totally *incompatible* with the milieu. We feel that these concepts offer a profitable alternative to determinism — either physical or social — for those interested in environments and behavior.

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Perception of High-density Living in Hong Kong

by LAWRENCE H. TRAVERS, *assistant professor, State University of New York, College of Arts and Science, Oswego, N. Y.*

ABSTRACT.—Analysis of the Hong Kong experience of adaptation to urban living can provide insights into some of the problems that can be expected to occur in the rapidly expanding cities of the Third World. Population densities in Hong Kong are among the highest in the world, exceeding 400,000 persons per square mile in parts of Kowloon. Research based upon residence in a worker's dormitory and interviews with workers reveals a variety of adaptive strategies employed by people to cope with the stress of the crowded urban environment. An understanding of the individual's ability to adjust to the stress of high-density living must consider the meaning of density as a concept in the culture in addition to social and cultural norms.

DESPITE DECADES OF CONCERN about the possible effects of high living densities upon human behavior, we know very little about mankind's ability to adapt to crowded conditions. Fears persist that the presence of a behavioral sink among rat populations forced to live in very crowded quarters *(Calhoun 1962)* might have a correlate in human populations. Perhaps rather than simply observing human behavior in dense conditions, we might more profitably attempt to uncover the meaning of different crowded living situations for individuals in different societies. Analysis of the perceptions, as well as the behavior, of the inhabitants of cities like Hong Kong might help us to understand better why some areas of the world already overcrowded by most standards fail to exhibit a true behavioral sink.

Information about the concept of density was obtained by interviewing young Chinese worker-students in Hong Kong. For eight months in 1973 I lived in a worker's dormitory in Ngau Tau Kok, site of several large public-housing estates for low-income families and resettled squatters. Impressions were gained by living as much as possible the life of the residents of the area, through informal conversations with many of the residents, and through structured interviews with cooperative individuals.

ACTUAL POPULATION DENSITIES

Densities in Hong Kong are among the highest in the world. In 1971 the Mongkok area in Kowloon had a density of 154,677 persons per square kilometer (or 400,612 persons per square mile) which is almost five times the living density of Manhattan Island *(H. K. Census & Statistics Dept. 1971)*. In the area studied, the average family of five lives in a single room of about 120 square feet. Although in the newer housing estates each room has its own toilet and cooking space, in the older estates washing and toilet facilities are communal and cooking is done on the exterio balcony which also serves as a corridor.

Though nearly half of the colony' population lives in such public housing in 1971 there were still almost 30,000 squatters on the rooftops and hillsides in the urban area and 35,000 living in areas about the size of a bed-space. Th congestion and crowded conditions in which nearly 4 million persons are living in less than 13 square miles of built up land must truly be seen to be believed.

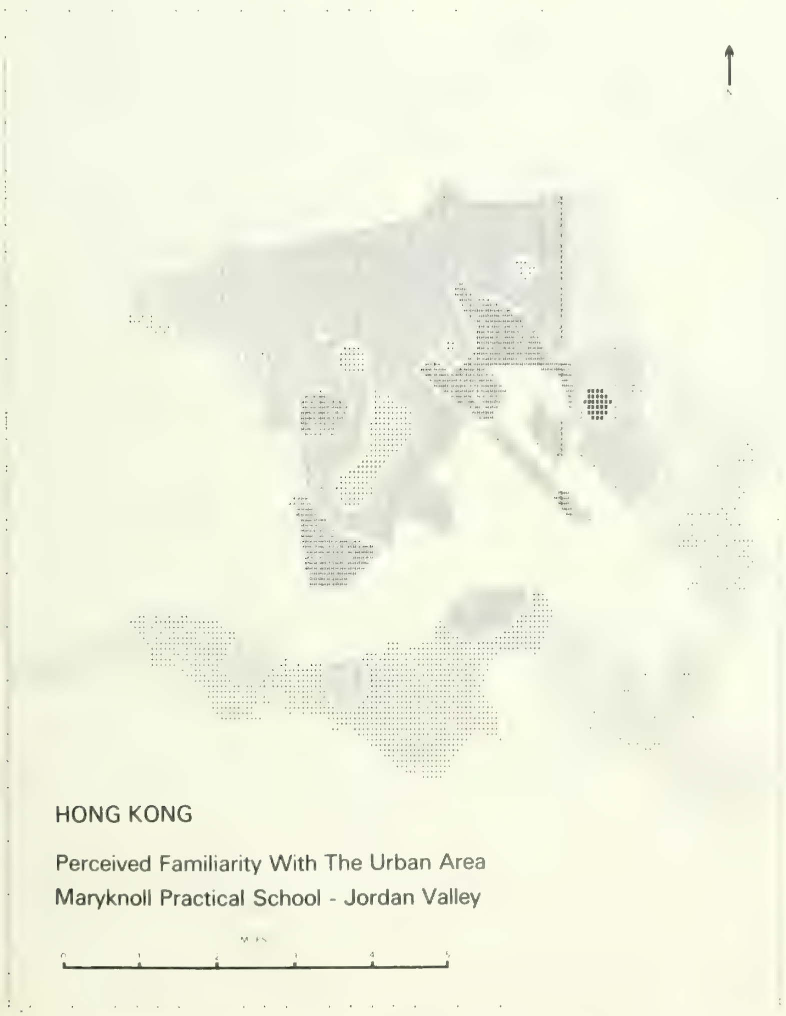
Crowded urban environments are, o

course, nothing new to the Chinese people. The Fengsheng neighborhood in Peking, considered to be fairly typical of other parts of that city, had a density of over 91,000 persons per square mile in 1972 *(Sidel 1974)*. Most of the buildings there were reported to be one- or two-story structures. Li Choh Ming *(1959)* has calculated that in 1957 the average housing space per capita in 175 Chinese cities was 3.5 square meters, varying from 4.9 in small cities to 2.2 in big cities. Of necessity Chinese both in China and in Hong Kong have learned to adapt to crowded living conditions.

PERCEPTION OF POPULATION DENSITY

To obtain comparable data about the Chinese perception of the urban area, 46 male adolescent workers attending evening classes at a secondary school in Kowloon were interviewed. Each was asked to indicate on a six-interval scale his familiarity with 58 urban districts (fig. 1). The students were then given a second questionnaire, which required them to estimate as best they could the average population density for the same 58 urban districts on a six-interval scale.

Figure 1.—Familiarity with the Hong Kong and Kowloon urban area; 46 workers attending a school marked by a dot have been averaged together. Darker shading indicates greater familiarity.


HONG KONG
Perceived Familiarity With The Urban Area
Maryknoll Practical School - Jordan Valley
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Estimations of the density of different parts of the urban area reflect knowledge of those areas obtained in several ways. Knowledge gained by travelling along the streets of the city, the "action space" concept of urban geography, can be termed experiential familiarity. Responses to both questionnaires clearly reflect this type of knowledge. A second type of familiarity, observational, is also apparent in the case of districts such as the Peak. Home of the Colony's most wealthy residents, the Peak can be seen from many parts of the city, and even if one has never been there it is not difficult to formulate ideas about the type of housing and number of persons living there. Observational familiarity plays an important role in forming the image of Hong Kong and Kowloon, twin cities separated by a deep harbor and fringed by hills.

Other parts of the urban area never visited nor observable from afar can still be known by what I have termed informational familiarity. Newspapers, television, and acquaintances are all sources of information about unfamiliar places in the city. Of course, most often what one knows of the city and of the population density of any particular part of it is an amalgam of these three types of familiarity. The individual is constantly bombarded with information; and while most is quickly forgotten, impressions of the urban environment remain.

Due to the fact that the format of the density questionnaire required an estimation of the population density, which might be unfamiliar to some individuals, it was necessary to weight each response to the density questionnaire by the individual's response to each item on the familiarity questionnaire. The students' estimations of the population density could then be averaged and mapped (fig. 2).

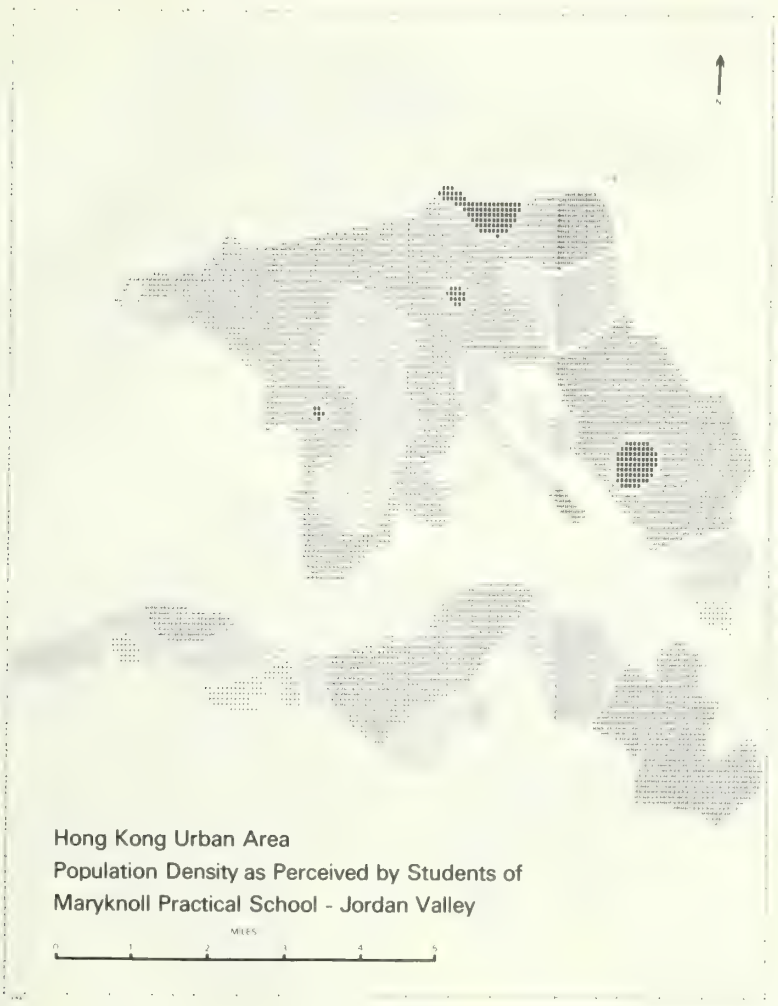
The averaged familiarity surface (fig. 1) indicates, as expected, that the district in which the school is located and where a majority of the students reside is most familiar. Major transportation corridors and business districts are well known; high-income residential areas, the urban fringe, and most of Hong Kong Island across the harbor are not very familiar.

The perceived population-density map (fig. 2) provides a generalized view of how these students view crowding and population density in their city. It indicates a high degree of uniformity as to which parts of the urban area are most crowded and which are least crowded. Surprisingly, the district in which most of the students live is not felt to be among the most crowded. This area, Ngau Tau Kok/Jordan Valley, had been selected for study because it was felt to be typical of the most densely populated residential areas in the city.

Assessment of the young worker-students' view of population density entailed comparing their perceptions with some measure of the actual population density for various parts of the city. This was accomplished by comparing the students' estimations with two very different measures of population density: net residential floor area per person and the number of persons per square kilometer for each urban district.

Net residential floor area per person is a measure of the degree of overcrowding in living quarters. It is calculated as one-half of the total floor area of a residential building, thus excluding kitchens, toilets, bathrooms, corridors, staircases, and landings. This information for 97 planning areas in the city was made available by the Crown Land & Survey Office of the Hong Kong Government. Aggregated to 58 districts and standardized, these data could then be compared with the standardized scores of the estimated population density, using Spearman's rank correlation. There is no similarity between the perceived and actual density measures for districts in Kowloon ($r_s = -0.06$) and

Figure 2.—The perception of urban area population density. Darker shading indicates more densely populated areas.


N
Hong Kong Urban Area
Population Density as Perceived by Students of
Maryknoll Practical School - Jordan Valley
MILES
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only minor similarity for districts located on Hong Kong Island ($r_s = 0.52$).

The population density perceived by worker-students is much closer to the other measure of density, the number of persons per square kilometer. The number of persons living in each city block was available from the 1971 Hong Kong Census of Population; the area of each of the 58 districts was measured, using a polar planimeter. Comparison of the perceived density measure with the number of persons per square kilometer shows a high degree of correlation. The similarity is highest for districts on Hong Kong Island ($r_s = 0.88$) and only slightly lower for districts in Kowloon ($r_s = 0.83$).

DISCUSSION

The fact that worker-students' perceptions of the urban population density closely approximates the actual number of persons per square kilometer reveals a very personal nature, are carried on in public, and neighbors often become involved.

Individuals spend as much time as possible outside the home, and many young adults return only to eat and sleep. Housewives shop in street markets at least twice daily, carrying their infants on their backs; young unmarried workers enroll in evening courses at schools; husbands returning home after working 10 hours escape into the fantasy world of television.

Some methods of coping with the crowded urban environment, on the other hand, show evidence of what might be called social pathologies. Despite the relatively low incidence of serious crime, many people live in a world of fear where every young male is believed to be a potential robber or mugger. The doors and windows of every home are barred with special steel gates; the city imprisons itself each night. Drugs and gambling are serious problems throughout much of the urban area. Little concern is shown for anyone in need who is not a relative or close friend. However, this social anomaly, often described by social workers and government officials, is probably not as much a result of the crowded living conditions as of the continued inability of most Chinese to identify with a foreign colonial government. Alienated from his homeland in China and uncertain of the future political status of the colony, many individuals have simply ceased caring about anyone outside the family.

CONCLUSION

The ability of Chinese, both young and old, to cope with the crowded living conditions that exist in most parts of Hong Kong is closely tied into the social fabric of Chinese society. Most people have made a successful adjustment to living densities that most Westerners would find intolerable. The ability of individuals and families in other societies to adjust to such high living densities in the rapidly growing cities of the Third World is difficult to predict because few places have yet experienced the densities of urban Hong Kong and Kowloon. Assessment of their ability to adjust must take into consideration the individuals' psychological perceptions of density in addition to the social and cultural norms of the society.

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Visual Land-use Compatibility and Scenic-resource Quality

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ABSTRACT.—The effect that land-use relationships have upon perceived quality of the visual landscape is discussed, and a case is made for expansion of fit-misfit theory into what has been called visual land-use compatibility. An assessment methodology that was designed to test people's perceptions of land-use relationships is presented and the results are discussed.

TRADITIONALLY, IN THE ANALYSIS of visual landscape quality, the parameters used most often are landscape diversity, landscape contrast, and landscape complexity *(Fabos 1973, Green 1972)*. In most of the assessment techniques, only the quantitative aspects of land-use adjacencies are considered. They consider only the length of the adjacency and degree of contrast between land uses. There is much evidence that people do indeed respond in a positive way to complexity and contrast *(Berlyne 1963, Day 1967, Munsinger and Kessen 1964, Lechart and Bakam 1965)*. Nonetheless, we are faced with the very real possibility that many of the land uses that contribute to contrast or complexity are themselves undesirable or are incompatible with other adjacent uses. This raises the need for a technique for qualitative assessment of land use relationships.

A review of historically related planning literature reveals that man has always been concerned with relationships between land uses in the development of communities. Early cities, for instance, were placed along or near bodies of water that provided the inhabitants with an adequate supply of water, transportation, waste disposal, and security from invading forces. This same need for security had a great influence on other development patterns. Forest land was not maintained immediately adjacent to communities because it provided concealment for attacking forces. Agricultural land on the outskirts of the cities not only provided necessary farm products, but also allowed ready observation of approaching visitors *(Mumford 1961)*. A less justified but nonetheless very real fear of the forest as a wilderness home of wild beasts and monsters further influenced the forest-town relationship *(Nash 1967)*. When the first Europeans arrived in America, the wild and natural environment they found reinforced these perceptions. Protection from the real and imagined enemies that lurked in the vast wilderness and development of farmlands led in part to the removal of much of the forest land throughout New England.

Late in the nineteenth century in the United States as well as Europe, perceptions of land-use relationships had begun to change. The romantic landscape movement in England and the subsequent park movement in the United States were the first evidences of these perceptual changes. In England, these movements were led by William Kent, Capability Brown, and Humphrey Repton. American leaders included Andrew Jackson Downing, Frederick Law Olmstead, and John Muir. By this time, people were beginning to see the value of natural elements in the landscape.

Early interest in land-use relationships was reflected in nuisance law. "While many land use incompatibilities are a product of physical damage flowing from close proximity, in many cases the conflict is predicted solely on matters of taste and preference rather than an observable physical effect" *(Mandelker 1970)*. By late in the nineteenth century, the separation of incompatible land uses had begun to take the form of present-day zoning. In the 1880s or 90s, Chinese laundry establishments in San Francisco were prohibited or restricted in certain parts of the city. When contested, the decisions were upheld in the courts as being valid use of the police power. Early in the twentieth century, zoning ordinances had become the common form of land-use regulation in the United States. The ordinance enacted in New York City in 1916 was the first of these *(Toll 1969)*. Since that time, zoning has become the most widely used method of land-use control and clearly represents a concern for the separation of what are perceived to be incompatible uses.

In developing methodologies for assessing metropolitan landscapes, land-use compatibility may be an important parameter. Although recent research has shown that land-use compatibility plays an insignificant role in influencing perception of visual quality at the natural end of the landscape continuum, *(Anderson et. al. 1976)*, it may play a major role at the urban end. This is explained by the fact that nearly all elements in a natural landscape are found to be compatible with one another, while the metropolitan landscape is made up of a variety of elements that are incompatible. Those rare element found in the natural landscape that ar incompatible with their surrounding can be treated as misfits. The occuranc of incompatible uses in the metropolita landscape is so frequent that they can not really be termed misfit. Thus th application of land-use compatibilit concepts to the metropolitan landscap can be thought of as an extension o misfit theory.

The research reported here was conducted to develop a methodology for assessing visual land-use compatibility i the metropolitan landscape. This research represents only a small part of larger ongoing project at the Universit of Massachusetts, called the Metropolitan Landscape Planning Project (METLAND).

METHODS

This research had three primary objectives. The first was to identify technique that could be used to determine compatibility values for possibl land-use adjacencies in the metropolita landscape. The second was to translat these values into a procedure for assigning actual scores to the landscape The third was to apply the entire procedure to a study area in the Bosto metropolitan area.

Although there is considerable literature about land-use compatibility, n clear technique for determining value exists. To resolve this problem, a testing procedure was designed. It wa hypothesized that the relationship between two adjacent land uses may b a function of the effect that each lan use has upon the other. That is, th relationship between land uses A and would be a function of the effect tha A has on B and the effect that B has o A. Furthermore, the effect of A on might be significantly different from th effect of B on A. For example, in consideration of a forest/residential adjacency, the effect of the forest upon th residential areas might be positive whil the effect of the residential area upon the forest might be negative. Thus the combination of these two effects could be considered a parameter of visual land-use compatibility.

The METLAND Study has used a land-use classification system generated from aerial photography by the Department of Forestry at the University of Massachusetts *(MacConnell 1972)*. Since its initial development, the system has been modified and expanded, and with the addition of several urban uses it now includes 126 distinct land types. This same classification system was used as a basis for the land-use compatibility component of the study. A few simple calculations show that this system generates an enormous number of land-use adjacencies. Using the formula

$$A = \frac{n^2 - n}{2}$$

where A is the total number of possible adjacencies, and n is the number of land uses, we find that there are 7,875 possible adjacencies. Obviously it is impossible to consider the visual compatibility of such a large number of adjacencies. Furthermore, the distinctions that can be made among many of these 126 land uses are relatively insignificant, especially with respect to visual characterstics. For instance, the difference between two forest types — H3A and H4A — is only in the heights of the trees, 30 feet and 40 feet respectively. Both are relatively mature forests, and he visual distinction is slight.

The first task was to find a technique for aggregating these 126 land uses into smaller number of common types. It eemed that the maximum number of adjacencies that could be considered was pproximately 100. This meant that he 126 types would need to be collapsed into 15 or fewer general classes (15 types would produce 110 adjacencies).

To accomplish this aggregation, a group of designers, planners, and resource managers were asked to sort 126 cards, each describing a land use, into 9 categories ranging from most man-made to most natural. Examination of the data received from this survey identified 10 distinct groups consisting of land uses with similar visual characteristics. For example, all of the land-use types that fell into the wetland category were obviously associated with water, consisted primarily of low vegetation, and lacked man-made structures; while those types that fell into the industry category were represented by large densely-built structures and a lack of vegetation or open land. An eleventh category, open water, was added because of its importance in influencing perceptions. These 11 general land-use groups, each representing a number of more specific land-use types having similar characteristics, were chosen for further study.

In any research of this nature, it is desirable to obtain as large a sample as possible. Generally the larger the sample, the more valid will be the results. However, other constraints such as limited personnel, finances, and time place restrictions upon the number of responses that can be obtained. For this study, it appeared that 50 responses was the maximum number that could be gathered in the time available and was an adequate number to achieve the desired results. To test a wide cross-section of the population, the 50 respondents were selected from 5 subgroups: designers (architects, landscape architects, and interior designers), planners (regional planners and community planners), realtors, conservationists, and nonprofessionals. It should be noted that nonprofessionals as used here is meant to include people who are not familiar with land-use related issues. Ten individuals from each of these 5 groups provided the sample of 50 respondents.

To elicit responses from participants, some sort of environmental stimulus is needed. This stimulus can be as simple as a written description, or as complex (to administer) as an actual on-site inspection. Again, time and money constraints greatly influenced our choice of a procedure. For this study black-and-white photographic prints of the eleven general land-use types were selected. Recognizing the difficulty in locating typical examples of each land use, we decided to produce 3 sets of photographs of the 11 general types.

An attempt was also made to control as many variables as possible in the photographs. The following criteria were used in selecting and photographing examples of land uses:

- All photographs were taken on sunny cloudless days in late spring between the hours of 10:00 a.m. and 2:00 p.m.
- Topographic relief was held constant in all photographs. Only sites with slightly rolling or flat topography were photographed.
- The amount of foreground was kept constant in all the photographs. This was accomplished by keeping the foreground line at the same position in the view finder of the camera for each photograph.
- The horizon line was kept constant in all the photographs.
- All photographs were taken from a normal viewer position.
- Each photograph was to represent only one land use.

To maintain consistency of procedure, all of the 50 surveys were administered by the author. Each participant in each subgroup was randomly assigned to one of the three sets of photographs so that 3 persons from each group responded to set A, 4 to set B, and 3 to set C. Each participant was shown all 11 photographs so that he or she would be familiar with the general land-use types. After this, one of the photographs, randomly selected, was placed on the participant's left. The remaining 10 photographs were then presented in a predetermined random order on the right. In all cases the participant was asked to respond to the following question:

> If the two land uses represented by the photographs you are observing were adjacent to one another, how would the land use on the right affect the visual quality of the land use on the left?

After all 10 photographs had appeared on the right, a different photograph was placed on the left, and the procedure was repeated until all 11 photographs had appeared on the left and had been compared with the other 10, making a total of 110 observations. The participants were asked to record their responses on the following scale:

—3 —2 —1 0 +1 +2 +3

If the land use represented by the photograph on the right had no effect upon the visual quality of the land use represented by the photograph on the left, the participant was asked to record his response in the space marked 0. If the one on the right enhanced the one on the left, the response would be recorded in the appropriate space on the positive side of the scale. If the one on the right detracted from the one on the left, the response would be recorded on the negative side of the scale.

FINDINGS

The results of the survey are presented here in two ways, first in relation to the consistency of the responses between the five subgroups and secondly, in relation to the actual compatibility values themselves. It was assumed at the outset that the extent of agreement among participants would not be the same for all of the adjacencies. To test this assumption, an analysis of variance was conducted to examine the variance between the 5 groups for each of the 110 observations (fig. 1). It should be noted that each relationship in the matrix, representing a possible adjacency, is derived from the combination of two observations. If there were no

Figure 1.—Extent of agreement matrix.

● HIGH AGREEMENT
◐ LOW AGREEMENT
○ NO AGREEMENT

	OPEN WATER	WETLAND	FOREST	AGRICULTURE	RECREATION	LOW DENSITY RESIDENTIAL	MEDIUM DENSITY RESIDENTIAL	HIGH DENSITY RESIDENTIAL	TRANSPORTATION	COMMERCIAL	INDUSTRIAL
OPEN WATER											
WETLANDS	◐										
FOREST	●	◐									
AGRICULTURE	●	●	●								
RECREATION	●	◐	●	◐							
LOW DENSITY RESIDENTIAL	●	○	●	◐	◐						
MEDIUM DENSITY RESIDENTIAL	◐	◐	◐	◐	●	●					
HIGH DENSITY RESIDENTIAL	●	◐	●	●	●	●	●				
TRANSPORTATION	●	◐	●	◐	●	●	◐	◐			
COMMERCIAL	●	◐	●	◐	◐	●	●	●	●		
INDUSTRIAL	●	○	◐	●	●	●	◐	●	●	●	

Figure 2.—Visual land-use compatability matrix.

● HIGH COMPATIBILITY
◐ MEDIUM COMPATIBILITY
⦶ LOW COMPATIBILITY
○ NO COMPATIBILITY

	OPEN WATER	WETLANDS	FOREST	AGRICULTURE	RECREATION	LOW DENSITY RESIDENTIAL	MEDIUM DENSITY RESIDENTIAL	HIGH DENSITY RESIDENTIAL	TRANSPORTATION	COMMERCIAL	INDUSTRIAL
OPEN WATER											
WETLANDS	●										
FOREST	●	●									
AGRICULTURE	●	●	●								
RECREATION	●	⦶	◐	◐							
LOW DENSITY RESIDENTIAL	⦶	⦶	◐	⦶	◐						
MEDIUM DENSITY RESIDENTIAL	⦶	⦶	⦶	○	◐	⦶					
HIGH DENSITY RESIDENTIAL	⦶	⦶	⦶	⦶	⦶	○	○				
TRANSPORTATION	⦶	⦶	⦶	⦶	○	○	○	○			
COMMERCIAL	○	○	○	○	○	○	○	○	○		
INDUSTRIAL	⦶	○	⦶	○	○	○	○	○	○	⦶	

disagreement between groups for either of the two observations, the agreement on that relationship was considered to be high; if there were disagreement between groups on one of the observations, the agreement on that relationship was considered to be low; and if there were disagreement between groups on both of the observations, there was considered to be no agreement on that relationship. There was considered to be disagreement on an observation when the scores from the 5 groups were found to be different at the 95-percent confidence level.

The actual compatibility values are recorded in figure 2. Again it should be noted that each of these values represents the scores obtained for two observations. The mean scores of all 50 participants for each of the 2 observations were added to derive the single value for each adjacency. The values were found to range from a low of −1.98 to a high of 4.78, which when normalized vary between 0 and 6.76. These values were then distributed into the four classes of visual land-use compatibility listed below:

High compatibility	4.51 - 6.76
Medium compatibility	3.01 - 4.50
Low compatibility	1.51 - 3.00
No compatibility	0 - 1.50

These visual land-use compatibility ratings (fig. 2) were applied to a preexisting assessment technique. A further discussion of that technique can be found in Fabos *(1973)* or Hendrix *(1973)*.

CONCLUSIONS

Several conclusions can be drawn from this study. It seems reasonable to expand the concept of *misfit* into a broader concept that expresses the relationships that exist between adjacent land uses. That is, people respond to all manner of relationships, not just to those that represent misfits.

This research was not designed to examine the multivariate aspects of land-use compatibility. The survey wa
made in such a way as to elicit response
about the visual aspect of compatibilit
only. In spite of this, several participants expressed concern for other aspect
while being interviewed. Housewive
for instance, commented about th
safety aspects of a housing and transportation adjacency. Similarly, man
participants seemed to be concerne
about other than visual aspects whe
confronted with an adjacency involvin
wetlands. While the developers expressed economic interests, the conservationists seemed to be concerned with pollutio
and loss of wildlife habitat. This ma
in part explain why there is so littl
agreement about wetlands adjacencie
between groups (fig. 1). It could b
concluded that more research, perhap
by environmental psychologists,
needed to resolve this problem.

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A Computerized Model for Integrating the Physical Environmental Factors into Metropolitan Landscape Planning

by JULIUS GY FABOS *and* KIMBALL H. FERRIS, *respectively professor in landscape planning and research associate, University of Massachusetts, Amherst, Mass.* *This study has been supported primarily by the University of Massachusetts Agricultural Experiment Station (Paper No. 1059). Additional support has been received from the U. S. Department of Interior Office of Water Resources Research and the USDA Forest Service, North-Eastern Forest Experiment Station, through the Pinchot Institute for Environmental Forestry Research, Consortium for Environmental Forestry Studies.*

ABSTRACT.—This paper justifies and illustrates (in simplified form) a landscape planning approach to the environmental management of the metropolitan landscape. The model utilizes a computerized assessment and mapping system, which exhibits a recent advancement in computer technology that allows for greater accuracy and the weighting of different values when mapping at the regional scale. It assesses resource, hazardous, and developmentally suitable areas in order to determine the consequences of development in these areas, and to channel development to the most environmentally appropriate of these areas.

PHYSICAL ASSESSMENT and planning models have traditionally been developed to deal with four aspects of landscape resources. These are quality, quantity, location, and distribution. When these four aspects of the physical environmental resources are known, decision-makers are able to make better trade-off decisions.

Landscape-planning procedures during the 1960s provided decision-makers with relatively useful composite maps showing where higher-quality landscape resource occurred in large quantities. These early planning processes, however, were not able to distinguish the values of the various resources. The computerized model described here represents a parametric approach to landscape planning that has the capability of weighting the values derived from perceived environmental quality. The model was designed primarily for those landscapes that are experiencing major development pressures at this time.

This paper is a summary of the most recent assessment model developed by a University of Massachusetts research team named METLAND. Its objective is to present an environmental/landscape assessment procedure that can be used to estimate: those special resource values thought to be essential for metropolitan population; potential natural and man-made hazards resulting from poor land-use decisions; an assessment of environmental opportunities for development termed developmental suitability and the production of an ecologically acceptable use type, development, density, and distribution plan of the Boston metropolitan region.

Since the second world war, metropolitanization has been one of the major contributors to environmental degradation. In contrast to the highly concentrated cities of the early industrial nations, which comprised only a few square miles, this new metropolitan growth extends its effects for several thousand square miles. Metropolitan regions are often interconnected to form megalopolitan regions such as the urbanized Northeastern Seaboard of the United States *(Gottman 1961)*. Since the 1950s this region has spread over more than 35,000 square miles of the landscape.

This mammoth metropolitanization has precipitated many undesirable side effects. It has eliminated or impaired untold acres of valuable natural resources such as water, upon which all life depends. Much of the development has occurred in areas subject to hazards such as flooding, noise, or air pollution. Developers selecting sites for development often did so in blatant disregrad of existing site characteristics. As a result, wetlands have been filled, unnecessary erosion problems have occurred, and developments have been located in climatically disadvantageous areas such as slopes facing into prevailing winter winds. Moreover, esthetic opportunities of developing areas have largely been ignored. Finally, the natural energy low of existing ecological systems has been seriously taxed because of an almost total lack of concern for basic ecological principles in the planning of metropolitan landscapes *(Odum 1969)*. n responding to these problems, a subfield of planning or regional design has merged under the name of *landscape lanning*.

The METLAND research group noted bove, comprised of over 16 researchers, concerned with these landscape-planning problems. The group has been developing and refining landscape-assessment procedures since 1971 *(Fabos 1973)*. These procedures are aimed at providing a meaningful and useful tool to aid all regions exposed to metropolitan growth pressures. More specifically, however, the study focuses on the problems of the Boston Metropolitan region, which has relentlessly expanded to engulf over 2,500 square miles, or almost half of the State of Massachusetts *(Ferris and Fabos 1974)*.

The model, although still in the process of development, is sufficiently advanced to show the step-by-step procedure used in its four components. The specific purpose of this paper is to put into perspective and illustrate in simplified form the significance of synthesizing the information generated by these components. Examples of some of the specific procedures for gathering assessment information may be seen in other METLAND papers included in these proceedings *(Caswell and Jakus, Fahrer and Peters, Hendrix,* and *Joyner and others)*.

An additional specific aim is to show the capabilities of the second generation computer graphic tools. These are used to integrate the values of the many landscape variables and the four components listed above and to study the cause-effect relationships of development and impact prior to implementation. In addition, these tools demonstrate how the existing research results of several disciplines can be used as input in an environmental or landscape-planning model.

IMPETUS FOR THE METLAND STUDY

The environmental or landscape planning considerations discussed here are certainly not new. Charles Eliot II, the founder of the first metropolitan system of parks, for example, frequently expressed great concern for the public values of wetlands, water and scenic values, during the late 19th century *(Newton 1971)*. The famous landscape planner, Benton MacKaye, voiced similar concerns during the 1920s *(MacKaye 1962)*. Nevertheless, systematic landscape resource, hazard, and suitability assessment was not practiced until the 1950s and 1960s.

One of the most outstanding members of this generation of landscape planners is Ian McHarg. In his book, *Design with Nature,* he proposed a generalized landscape approach for assessing large landscape such as metropolitan regions *(McHarg 1969)*.

Simultaneously, by the late 1960s the first generation of computer graphic techniques was being widely used for the data manipulation of landscape variables *(IRIS 1972)*. This technique was applied manually by overlaying a grid on the various resource and data maps of a given region. For each grid cell several types of resource data were processed into the computer. Once in this form, the data could be manipulated to provide print-outs of assessment maps. This technique is still valuable for some generalized regional assessment such as air pollution. It is less useful, however, for manipulating more detailed data such as soil, vegetation, or land-use types.

Remote-sensing capabilities and other land-use survey techniques also began providing landscape planners with relatively accurate data during this period. Although the data were quite accurate, the smallest land-use map units (grid cells) which could be realistically prepared by the computer use from airphotos were about one hectare *(MacConnell 1956)*.

Soils, surficial geologic, and other pertinent environmental data were also available at a high degree of accuracy, but they too could be practically manipulated only at the 1-hectare size. While all these pieces of information are meaningful for landscape resource, hazard, and suitability assessment, the first generation 1-hectare grid cell is too gross to assess them accurately. If grid cells smaller than 1-hectare were used in this process, the data processing would be overly costly and extremely tedious.

For this reason the METLAND team searched for computer software more responsive to its landscape-planning needs. Among all the computer graphic techniques surveyed in 1973, the Computer Mapping for Land Use Planning (COMLUP) system *(Allen 1973)* seemed most appropriate for our study.

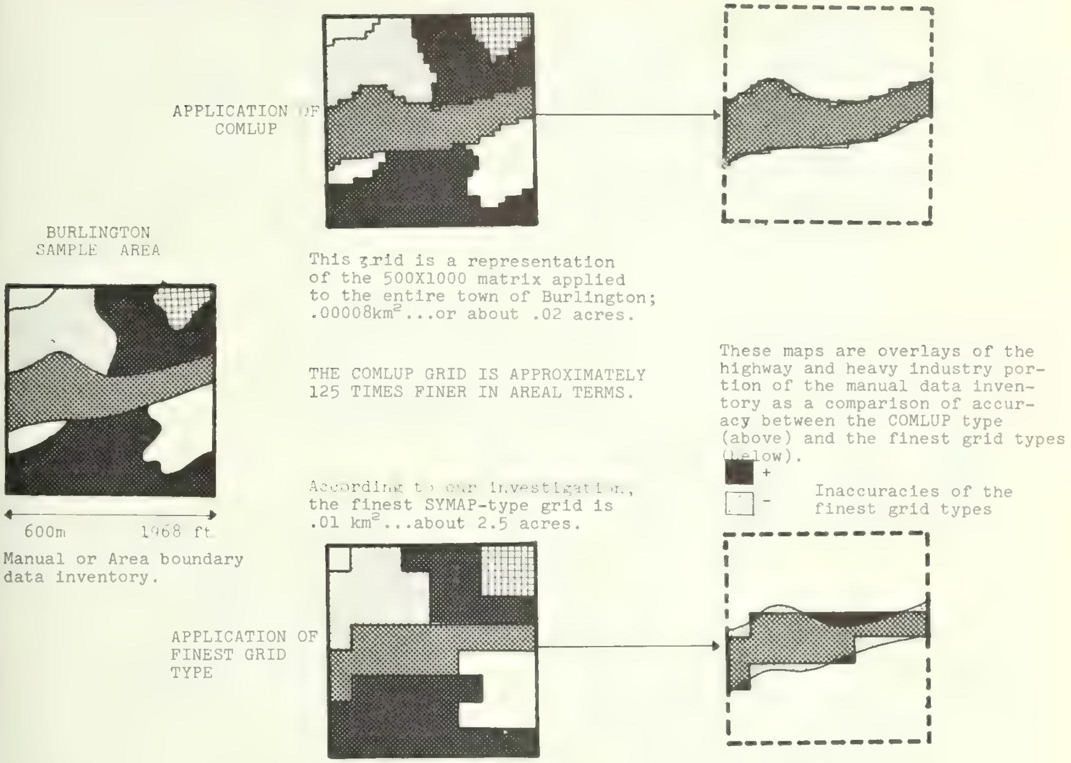
The advantage of this computer graphic technique is that any shape and size of polygon can be directly input and stored in the computer, by image digitizer, without subdividing the polygon into grid cells. For data manipulation, the digitized area still must be subdivided into cells, but this is now done in a second step by the computer automatically, instead of as a first step and manually. In addition a much finer cell granularity with a grid matrix of 500 X 1,000 cells is now possible.

Figure 1 shows the advantage in accuracy of COMLUP (an example of this second generation) over the first-generation computer grid technique when applied at the regional scale. With this new capability the more accurate data being produced may be better used by landscape planners.

While landscape planners are utilizing this second generation of technology computer programmers are working on a third generation, which is being designed to overlay polygon areas directly without the interim step of converting i back to grid cells for manipulation. Th Canada Geographic Information System Group of the Canadian Federal Government and the U.S. research firm Raytheon are among those in the process of developing this more advanced third generation of computer graphic software systems.

The remainder of this paper focuse on the METLAND environmental/landscape-palnning model, with special emphasis on the assessment procedure including some sample results. Th model is presented by first examining it

Figure 1.—The relative accuracy of the first generation (grid type) and second generation (modified grid type) computer mapping systems when applied at the same regional scale.



This grid is a representation of the 500X1000 matrix applied to the entire town of Burlington; .00008km^2...or about .02 acres.

THE COMLUP GRID IS APPROXIMATELY 125 TIMES FINER IN AREAL TERMS.

According to our investigation, the finest SYMAP-type grid is .01 km^2...about 2.5 acres.

Manual or Area boundary data inventory.

These maps are overlays of the highway and heavy industry portion of the manual data inventory as a comparison of accuracy between the COMLUP type (above) and the finest grid types (below).

Inaccuracies of the finest grid types

overall framework. Then the synthesis of the special resources component of the assessment phase is presented, and the significance of the results is discussed. A comprehensive report is now being prepared on the entire assessment procedure.

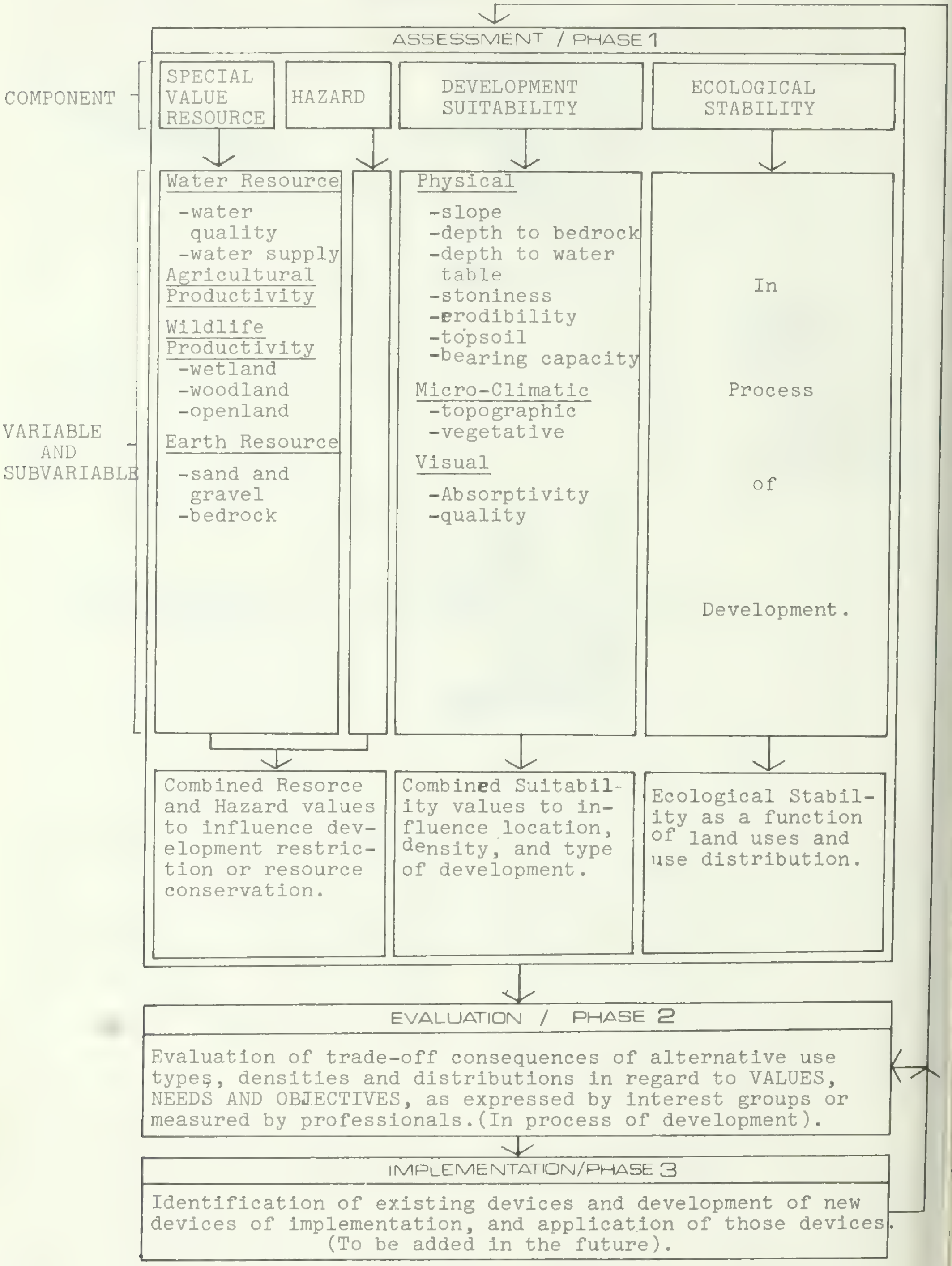
FRAMEWORK OF THE METLAND (ENVIRONMENTAL/LANDSCAPE) PLANNING MODEL

To deal adequately with environmental issues of the metropolitanized landscape, the METLAND team has proposed a three-phase planning model including assessment, evaluation, and implementation phases (fig. 2). At this point the assessment phase is close to completion, and some work has begun on the evaluation phase; the implementation phase is planned for later development.

The assessment phase consists of a selection of variables analyzing the intrinsic value of landscape resources which may provide societal benefits. This phase also analyzes natural or man-effected hazards that may cause harm to people or property. These several resource and hazard analyses are mapped and organized into four groups, called components. While each individual variable has a specific value, this grouping helps to identify complementary relationships and to provide combined values, which are useful in making decisions. The four components of the assessment phase are: special value resources, hazards, development suitability, and ecological stability.

The special value resource component (fig. 2) includes those natural renewable, nonrenewable, and esthetic resources whose maintenance is essential

Figure 2.—The structural framework of the METLAND (Environmental/Landscape) Planning Model.



Combined Resorce and Hazard values to influence development restriction or resource conservation.

Combined Suitability values to influence location, density, and type of development.

Ecological Stability as a function of land uses and use distribution.

Evaluation of trade-off consequences of alternative use types, densities and distributions in regard to VALUES, NEEDS AND OBJECTIVES, as expressed by interest groups or measured by professionals.(In process of development).

Identification of existing devices and development of new devices of implementation, and application of those devices. (To be added in the future).

for metropolitan populations. Development of these resource areas would eliminate or greatly impair their value. Though these resources are ubiquitous, their quality and quantity range from the insignificent to the critical. The assessment of this component is based on the premise that if a portion of a landscape possesses high quality and quantity of one or more of these resources, those areas should receive special consideration or even protection from development. If immediate need for the resources is not apparent, they should be protected or conserved much as capital resources are saved in a bank until they are needed.

The hazard component (fig. 2) includes air and noise pollution, both of which are direct human byproducts, and flood hazard which, although it is a natural phenomenon, is both aggravated and intensified by human activity. Flooding becomes harmful only when development is in nature's way.

The assessment of these three hazard component variables provides spatial information on both the type and magnitude of hazards. Areas where one or more hazards occur are obviously less valuable for development than areas free from hazards. This is true even if the harmful effects may be corrected, because those corrective devices are usually very costly and often ineffective. In short, the assessments of special-value resources and hazards imply development restrictions in those portions of the metropolitan landscape where assessed values or hazards are high.

The development suitability component is the obverse of the previous two components. Its objective is to identify the most suitable areas for development from the point of view of physical, climatic, and visual characteristics. Highly suitable areas for development are less costly to build upon and provide increased amenities and comfort when developed.

The ecological stability component represents another essential consideration. Exploration of special resource-value areas, such as gravel quarries, production of environmental hazards such as air pollution, and even extensive development on highly suitable lands may have greater negative effects on the metropolitan ecosystem than desired. A preliminary objective of this component is to determine the amount and distribution of land uses in what Odum *(1969)* terms "protective", "productive", "compromise" (suburban), and "urban-industrial" zones. One purpose of this classification would be to understand the structure and function of the land uses within these zones. (The research in this component began only recently and as yet is not as developed as that of the other components.)

Detailed analysis and substantiation of values is conducted at the variable and subvariable level of phase I (fig. 2). Although original research to substantiate values is infrequently conducted, normally the team is dependent on the research finding of other scientists. For example, in the case of the *physical variable* of the development suitability component, values have been derived from the work of environmental geologists such as Flawn *(1970)*, scientists of the Soils Conservation Service *(Bartelli et al. 1966)*, or cost estimates of builders *McKeever 1968)*.

From these kinds of research results, the significance and magnitude of such subvariables as degree of slope or depth to water table for various developments are estimated. The resulting suitability assessments are analyzed in regard to short-range effects on construction costs to the developer, and long-range effects of these costs both to the community (e.g., in the form of siltation problems) and to the occupant (who in the case of high water table, would frequently need to pump water out of his basement.)

PARTIAL APPLICATION OF THE ASSESSMENT PHASE

Before we discuss the results of the application and synthesis of qualitative environmental assessments, a discussion of the preparation of data used in the step-by-step procedure used in the COMLUP computer manipulation is desirable. As mentioned earlier, the Computer Mapping for Land Use Planning (COMLUP) system of USDA Forest Service is the system used and adopted in the assessment phase.

DATA Preparation and the COMLUP Process

All of the assessment procedures in all of the assessment components are essentially composed of two elements: pregathered data in mapped form and the manipulation of those data according to a defined metric. The data are obtained from reliable sources. For example, the Soil Conservation Service supplies detailed soils maps or the U.S. Geologic Survey provides data obtained from aerial photogrammetry and ground truth validation.

These data are termed source maps for the purposes of the METLAND study. They are manipulated and aggregated in different ways according to the precise requirements of each assessment variable and its metric needs. Nevertheless, the procedure for the preparation of these source maps for manipulation, the actual procedure for manipulation, and the procedure for the final plotting of variable assessment maps is common to all. That procedure is basically as follows:

STEP 1: Digitize, edit and store on magnetic tape all the information contained on the source maps. (This is the function of the first third of the COMLUP programs.)

STEP 2: Aggregate the digitized source-map data according to the needs of the variable or subvariable assessment procedure, and make any overlays that are required by that procedure. (Second third of COMLUP.)

STEP 3: Plot the results. (Final third of COMLUP.)

Internally the COMLUP programs take the digitized data in line-segment form and overlay a grid of extremely fine granularity (500 x 1000 cells) on those data. With the data in this gridded format, the overlays required in Step 2 may be made with no difficulty. Step 3 reconverts these data to line format so that they may be plotted on a drum or flat-bed plotter. It would also be possible to use some of the newer plotting techniques such as three-dimensional plotting of the SYMVU type if desired.

Some Composite Results and Planning Considerations

Of the four components noted above, the special-value-resource component was selected to illustrate the resuts of synthesizing the assessment values. Assessments utilizing the COMLUP technique were prepared for four special-resource-value areas: agricultural productivity, wildlife productivity, water resources, and sand and gravel. These were composited for two points in time — 1952 and 1971 *(Fabos 1973)*.

Early landscape-planning procedures simply identified landscape values or hazard potentials. When they were thought to be significant they were handled as co-equals (each having equal importance). Resulting high- and low-value areas could be depicted.

With the numerous problems sure to beset us in the last quarter of this century, it will become increasingly difficult to defend environmental landscape values, when pressured for trade-offs by economical, political, and social values by simple statements such as high value, as concluded by the landscape approach. When making trade-off decisions, most commonly accepted values are expressed in monetary terms.

A pound of meat costs more than a pound of bread, even though both are of high value as food. Similarly, value differences exist among special environmental resources and all other categories discussed.

It ha been implied that these value differences can be based on social/political and economic values. Political decisions often express composite values of subgroups or interest groups of the society. Through survey research techniques and observation, planners can estimate the values of pertinent subgroups. Economists also have developed numerous procedures to distinguish among values.

In environmental planning, several sets of values should be established. Social/political and economic values should be expressed for both short-range and long-range goals. Though planners have experimented with this idea, prior to the advancement of the parametric planning approach, the adaptation of this concept to decision-making was not feasible. In the near future, however, the rapid computerized, quantitative information of the consequences of tradeoffs among alternative sets of values will be readily available for decision makers.

To illustrate how a single-purpose value differentiation can provide an input to environmental/landscape planning, the value differences among the assessed special resources are shown in figure 3 in economic terms. The resource economists of the METLAND team (Foster, Torla, and Whaley) have provided value estimates for the resource, hazard, and development suitability variables listed under the heading phase I in figure 2.

The preparation of the composite special-resource-value map is similar to that used in the landscape approach. As a first step, high yield and quality water-resource areas, high-quality and usable agriculture lands, areas of high-quality wildlife, and areas with good sand and gravel potential were located and mapped.

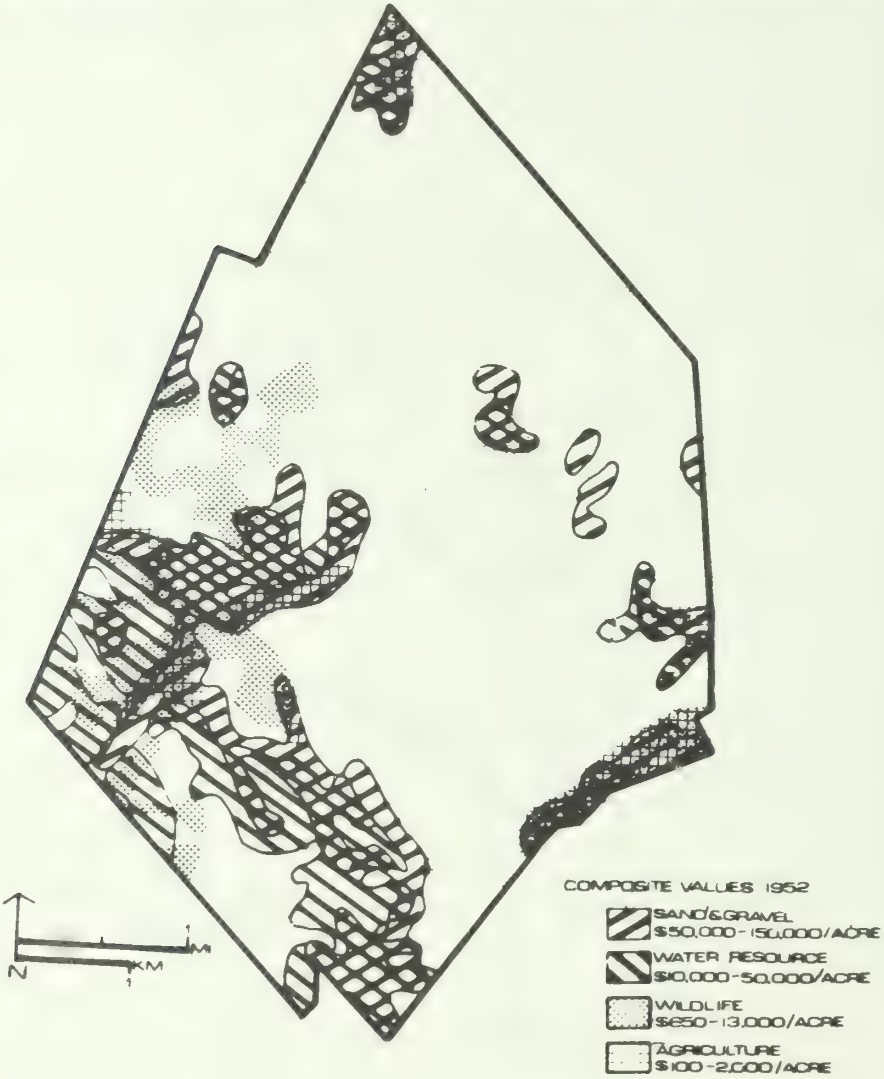
The difference between this and the landscape-planning approach, however, is twofold. First, the overlaying process is done rapidly and accurately by computer; and second, each area with high values may be assessed in terms of the estimated combined dollar value of the resource present.

Because of the scale of the maps presented in figure 3, the composite map has been simplified for visual display. Instead of the actual estimates, only ranges from low to high values are shown. The computer, however, is capable of calculating the composite estimate values per acre or per parcel of each combination.

The composite values of the special resources shown in figure 3 are most impressive. If these values, which are estimates, were confirmed, the cost of metropolitan growth, when implemented without regard to environmental values, would be shown to be very high indeed. The reader is cautioned, however, not to take these value estimates as conclusive evidence of resource loss. A more appropriate use of this information lies in two areas. First, when probable areas of resource-value concentration are known, growth can be directed away from these areas, assuming that sufficient alternative land is available. When and if at a later date these values are confirmed by detailed assessment techniques, such as drilling to find out actual depth and quality of sand and gravel resources, more permanent management decisions may be made for their use.

A second consideration in the use of this information lies in the recognition that these overlapping values are not always additive. For example, excavation of sand and gravel in areas of high water-supply potential may impair the rechargeability of ground water or destroy certain wildlife-habitat areas. As

Figure 3.—This simplified composite special-resource-value assessment illustrates an application of the parametic approach to Burlington, Massachusetts. The values listed are estimates of 1952 composite resource values. These estimated values range from $100/acre to a possible $203,300/acre (where water, wildlife, agriculture, and sand and gravel resource areas overlap). Notice that a great portion of these valuable resource areas were developed by housing, commercial, and industrial uses from 1952 to 1971. The impact on these areas led to an estimated loss of over $30 million dollars in foregone special-resource value.



N
1
MI
KM
1
COMPOSITE VALUES 1952
SAND&GRAVEL $50,000-150,000/ACRE
WATER RESOURCE $10,000-50,000/ACRE
WILDLIFE $650-13,000/ACRE
AGRICULTURE $100-2,000/ACRE

a result, the value of the area may not represent the sum of the value of each resource when considered individually.

The significant point to be gleaned from this information is that models are being constructed to examine these relationships and environmental/landscape parameters. The METLAND model illustrated here is a reflection of the dynamic nature of this new field. Both are growing rapidly in an effort to deal with the problem of decentralized metropolitan growth. The example illustrated here portrays an interim step, useful today, while the more sophisticated computer assessment techniques are being developed.

We believe that this new parametric

approach will provide better and more diversified information on the qualitative aspects of the environment to decision-makers. Resource qualities and quantities together, with their location and distribution patterns, may now be assessed and manipulated by this process which, we believe, is a significant improvement in the state of the art of physical/landscape planning.

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Use of the Delphi Method for Determining Community Growth Goals Inventory: The Nashville Experience

by VISHWA K. VARMA, *regional manager, American Consulting Services, Franklin, Tenn.; and was director, Environmental Review Office, Metropolitan Government of Nashville and Davidson County, Nashville, Tenn. when this paper was presented.*

ABSTRACT.—The author discusses the growth-inducing pressures on Nashville, Tennessee, describes the application of the Delphi technique to develop an inventory of the community's growth goals, and suggests that the development of a list of community goals is a necessary first step toward growth management.

GOALS AND THE CONCERN FOR THE FUTURE

HAVING A CONCEPT of the future and seeking a better tomorrow, man sets goals and then attempts to influence his environment toward attaining them. A goal is the beginning of a problem, in that a problem is an unmet goal. Without a goal, a problem does not exist.

Today the urban centers of America are faced with several unmet needs and unsolved problems. Problems of economy and ecology seem to loom larger than ever.

These problems exist in spite of the fact that an estimated 85 percent of all the scientists that have ever lived on earth are living in our day and age. These problems are in direct contradiction to the prophecy made in 1936 about life in 1960 and beyond *(Langdon-Davies 1936)*:

> "... food, clothing, and shelter will cost as little as air ... and there will be room for all, rent free ... Science has only to go a few steps farther ..."

The concern for these problems is a concern for our future — and that of our children. Many cities in the U.S.A. are faced with this concern as they find a prematurely arrived future at their doorsteps.

THE SETTING IN NASHVILLE

In the United States, 75 percent of the people live on approximately 3 percent of the land — mainly in urban centers. Nashville, Tennessee, is one of these centers. The leadership of Nashville has voiced its concern for building a viable future for Nashville. They have asked themselves several questions. Do we, as a city, know what we want our future to be? Are we prepared for the future? For instance, in his 1974 state-of metro address, former Mayor Beverly Briley exhorted Nashvillians to "believe in and strive for a future we may not see," and announced the formation of a Nashville 2001 Citizens' Goals Committee.

Nashville has a consolidated city-county metropolitan type of government. It came into being in 1962, bringing with it a single government with county-wide jurisdiction instead of the six city governments that existed in Davidson County before consolidation.

Nashville is the capital city of Tennessee and the economic and population center of the 13-county Mid-Cumberland Development District. With a population of 460,000, Nashville accounts for 56 percent of the region's population. It is also the main trade center of the

Mid-Cumberland Region as well as its financial and medical services hub. It has a balanced and diversified economy of industrial and commercial development. Its tourist and entertainment traffic, based primarily on its reputation as "Music City, USA," will probably, increase after release of the movie *Nashville!*

In 1973 the Academy for Contemporary Problems projected Nashville to be one of 28 urban centers where 90 percent of the American population will be centered in the year 2000. Several developments are now taking place around Nashville that do indeed portend a substantial growth in and around it. In December 1972, construction began on the Tombigbee Waterway. This massive waterway, funded by federal funds and scheduled for completion in 1981, will in effect connect Alabama, Mississippi, Tennessee, and Kentucky to the Gulf of Mexico and hence to world markets. During the last year work has begun on a 3-billion-dollar nuclear power facility for the Tennessee Valley Authority. This power plant will be located in Hartsville, just 25 miles east of Nashville. With 13 major colleges and universities, 5 major hospitals, the bulk of the country music industry, and six legs of major interstate highways, Nashville is faced with inevitable growth in the coming years.

The choice, for Nashville's decisionmakers, is not between growth and no growth, but rather between disorderly growth and managed growth.

NASHVILLE'S EXPERIMENT WITH THE DELPHI TECHNIQUE

This issue of growth has been addressed by many groups and organizations in Nashville and Davidson County during the past few years. In July 1972, an Environmental Planning and Management Project was started in Nashville with a grant from the Ford Foundation *(elling 1974)*. The Project's objective was to develop a strategic environmental problem-solving capability in the local government system, while recognizing the citizens' increasing concern about not only the quantity of growth but also the quality of that growth.

Last year the Environmental Planning and Management Project attempted to develop an inventory of community goals. The objective of this experimental undertaking was to identify a series of goals as articulated by Nashville's opinion leaders. It was decided to use a modified Delphi technique to achieve this objective.

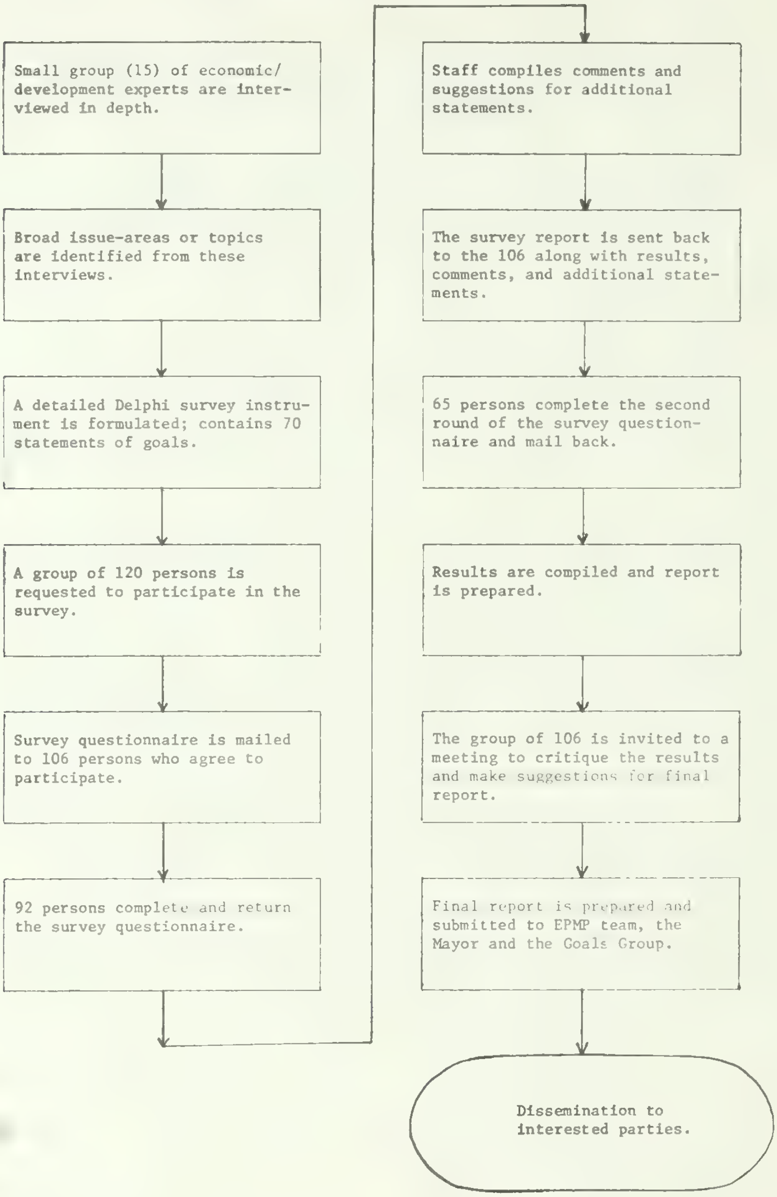
The most frequent use of the Delphi technique has been to obtain expert consensus about the likely time of occurrence of some future event. Lately, the term "Policy Delphi" has been used to describe experiments in which researchers have tried to identify policy options on general issues. The major difficulty encountered in such Delphi experiments is with the adequacy of the description of policies. A certain amount of generality or ambiguity is always inherent in these Delphi statements, and each expert's interpretations embellish it to the point that the statements are too general to be policy guides or too specific for a wide variety of experts to comment on.

In the Nashville experiment, the Delphi technique was used primarily to collect data in which the data-gatherer acts as an objective collator of the opinions of others. Specifically, the modified Delphi consisted of the following steps (fig. 1):

Step 1.—A small group of 15 developmental experts was subjected to in-depth interviews. This group included economists, developmental experts, urban planners, elected officials, bankers, engineers, and investment experts. The interviews were taped and conducted by a retired newspaper reporter who had covered city affairs for the past 35 years. Open-ended questions were used. The purpose was to surface issues and aspects around the city's future.

Step 2.—A staff team conducted an

Figure 1.—Plan and sequence of the Delphi technique used in Nashville.


Small group (15) of economic/development experts are interviewed in depth.
Broad issue-areas or topics are identified from these interviews.
A detailed Delphi survey instrument is formulated; contains 70 statements of goals.
A group of 120 persons is requested to participate in the survey.
Survey questionnaire is mailed to 106 persons who agree to participate.
92 persons complete and return the survey questionnaire.
Staff compiles comments and suggestions for additional statements.
The survey report is sent back to the 106 along with results, comments, and additional statements.
65 persons complete the second round of the survey questionnaire and mail back.
Results are compiled and report is prepared.
The group of 106 is invited to a meeting to critique the results and make suggestions for final report.
Final report is prepared and submitted to EPMP team, the Mayor and the Goals Group.
Dissemination to interested parties.

analysis of transcripts from Step 1. A list of broad issues and goal-type statements was developed. A detailed list of community goals, containing 69 statements, was developed.

Step 3.—A Delphi questionnaire was developed from the list of goals. The questionnaire sought responses on (1) the level of importance of a goal statement and (2) how much needs to be done to reach the goal. To obtain these two pieces of data, the respondents were asked to rate each goal on its present status and desired future status.

Step 4.—A group of 120 opinion leaders was invited to participate in this survey. The method of selection was as follows: The Mayor invited all professional associations, clubs, citizen bodies, civic groups, public interest groups, religious and business organizations, League of Women Voters, Sierra Club, etc., and the general citizenry to send him nominations for the Nashville 2001, Citizens' Goals Committee. More than 600 names were received. The project staff was allowed access to this list. After eliminating duplications and selecting for a cross-sectional representation, a list of 120 opinion leaders was selected. Of these 106 agreed to participate in the Delphi survey.

Step 5.—Delphi questionnaires were mailed to 106 persons.

Step 6.—The returns (92 out of 106) were tabulated, and step 5 was repeated. This time, respondents got summary results of how others rated the various goals and had a chance to revise their assessments. The returns were again tabulated and comments collated. The final report was prepared and presented to the Mayor and the Citizens' Goals Committee. After the first round, an additional nine goal statements were added on to the inventory of community goals.

RESULTS AND CONCLUSIONS

Through this process, 78 goal statements were generated. Each falls into one of the following areas:

1. Governance
2. Regional cooperation
3. Economic and community development
4. Recreational, leisure, and cultural resources
5. Public education
6. Human resource development
7. Transportation
8. Public safety/crime prevention/justice system
9. Environment
10. Housing

Overall mean scores after round two or these categories showed that housing, environment, and public safety vere the top three issues. Also, if the

Table I.—Overall mean scores and differences

Status	Environment	Housing	Transportation	Public safety	Public education	Human resource development	Recreational resources	Regional aspects & relations	Economic community development	Governmental services & concerns
					ROUND 1					
Desired	4.057	3.857	3.617	3.799	3.848	3.630	3.202	3.708	3.905	3.467
Present	2.726	2.333	2.350	2.514	2.385	2.457	2.557	2.393	2.677	2.171
Difference	1.331	1.524	1.267	1.285	1.463	1.173	0.645	1.315	1.228	1.290
					ROUND 2					
Desired	4.140	4.533	3.617	4.102	3.733	3.723	3.106	3.733	3.989	3.560
Present	2.746	2.288	2.350	2.673	2.706	2.486	2.700	2.570	2.818	2.208
Difference	1.394	2.245	1.267	1.429	1.027	1.237	0.406	1.163	1.171	1.352

Figure 2.—A comparative analysis of goals by ranking of differences.

COMPARATIVE ANALYSIS BY RANKING OF DIFFERENCES (D-P)			PROFESSION				INCOME			LENGTH OF RESIDENCE			RACE	
	Ranking by mean of difference	*Overall*	*Government services*	*Retired and housewives*	*Business*	*Professionals*	*Low*	*Medium*	*High*	*Less than 10 years*		*More than 39 years*	*Caucasian*	*Blacks*
2. HOUSING	(1)	1	1	2	1	3	1	1	3	4	1	1	2	1
	D / P	3 / 9	5 / 9	3 / 9	3 / 7	5 / 8	3 / 9	3 / 7	6 / 7	5 / 7	5 / 9	1 / 8	5 / 9	1 / 10
5. PUBLIC EDUCATION	(9)	2	3	1	5	2	2	3	2	3	3	2	1	3
	D / P	4 / 7	3 / 7	1 / 10	6 / 8	1 / 6	2 / 7	4 / 6	3 / 10	3 / 6	3 / 7	4 / 9	3 / 8	2 / 4
1. ENVIRONMENT	(3)	3	6	3	3	6	6	8	1	6	2	8	4	10
	D / P	1 / 1	2 / 1	2 / 4	1 / 1	4 / 3	1 / 2	1 / 1	1 / 8	1 / 1	1 / 6	2 / 1	1 / 1	8 / 1
8. REGIONAL ASPECTS AND RELATIONS	(8)	4	2	4	8	1	5	2	9	2	6	4	5	7
	D / P	6 / 6	1 / 6	5 / 7	8 / 5	2 / 9	6 / 8	6 / 9	7 / 2	4 / 8	6 / 6	6 / 7	6 / 6	9 / 8
4. PUBLIC SAFETY	(2)	5	5	7	6	5	4	6	4	8	4	3	3	6
	D / P	5 / 4	6 / 4	6 / 6	4 / 4	3 / 4	5 / 5	5 / 5	5 / 5	7 / 5	4 / 4	5 / 4	4 / 5	6 / 6
3. TRANSPORTATION	(5)	6	7	9	2	8	8	4	8	1	9	6	8	5
	D / P	8 / 8	9 / 8	8 / 2	5 / 9	8 / 7	8 / 6	8 / 8	8 / 4	6 / 7	9 / 8	7 / 6	7 / 7	7 / 7
10. GOVERNMENT SERVICES AND CONCERNS	(4)	7	4	5	7	4	3	5	7	5	5	7	6	2
	D / P	9 / 10	7 / 10	9 / 10	9 / 10	9 / 10	9 / 10	9 / 10	9 / 10	9 / 10	7 / 10	9 / 10	9 / 10	5 / 9
9. ECONOMIC COMMUNITY DEVELOPMENT	(7)	8	8	8	4	9	9	7	5	7	7	5	7	8
	D / P	2 / 2	4 / 2	7 / 1	2 / 2	6 / 2	4 / 1	2 / 2	2 / 1	2 / 2	2 / 2	3 / 2	2 / 2	3 / 2
6. HUMAN RESOURCE DEVELOPMENT	(6)	9	9	6	9	7	7	9	6	9	8	9	9	4
	D / P	7 / 5	8 / 5	4 / 5	7 / 3	7 / 5	7 / 4	7 / 4	4 / 3	8 / 4	7 / 5	8 / 3	8 / 3	4 / 5
7. RECREATIONAL RESOURCES	(10)	10	10	10	10	10	10	10	10	10	10	10	10	9
	D / P	10 / 3	10 / 3	10 / 3	10 / 6	10 / 1	10 / 3	10 / 3	10 / 6	10 / 3	10 / 3	10 / 5	10 / 4	10 / 3

difference between desired status and present status is used as a measure of how far we've got to go to get where we want to be, even then the same three issues are on top. This time, however, the order is slightly different: housing, public safety, and environment (table 1).

A more detailed analysis was done on the basis of (1) profession, (2) income, (3) length of residence in Davidson County, and (4) race (fig. 2). For Blacks, housing and governmental services were the most important goal areas, as measured by the mean difference between present and desired status scores. By the same measure and for the same group, environment ranked tenth, while its rating by the total group was third.

In transportation, the two subgroups that attach high importance (by mean of difference between present and desired) to this are (1) businessmen and (2) relative newcomers to the community.

The main accomplishment of this experiment was the starting of a community-based process for looking at Nashville's future. It has developed an awareness for goal-setting as a basis for growth-management.

True, the survey itself was not as statistically clean as a researcher might have desired it to be. But then, it was undertaken by practitioners, not academicians. Consequently, there are several caveats. The most important, of course, is the admonition that the dynamics of the process were more important than the output. More time could have been spent on making the statements more substantive.

The Delphi technique has tremendous value as an educational device for planners, particularly policy planners. That is its prime benefit in Nashville. It obviously obtained citizen input through a very representative group. In fact, it could be expanded to cover wider segments of population.

The technique may have more use if used on an ongoing basis. Goals should not be considered one at a time, nor should they be thought of as set for all time to come. Goals are as dynamic as the human experience. As goals are reached, visions are broadened and yet more difficult and numerous goals are set.

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Techniques of Data Analysis and Presentation for Planners of the Metropolitan Environment

by JOELEE NORMAND, *Department of Meteorology, University of Oklahoma, Norman, Okla.*

ABSTRACT.—Relationships between the characteristics of the physical environment of a metropolitan area and the activities of its human inhabitants can be used to predict probable future dynamic trends, both demographic and environmental. Using simple linear regression, we were able to highlight several dynamic features of the metropolitan area of Tulsa, Oklahoma. Computer movies of the growth of Tulsa and attendant air-pollution problems were used for showing demographic and physical features simultaneously to facilitate the information-assimilation process so critical to planning.

THE NEED FOR ASSIMILATION of large quantities of data is critical to decision-makers in metropolitan environmental planning. The rapid and effective transfer of technology from the scientific and engineering fields to the urban-planning field is the purpose of the studies presented in this paper.

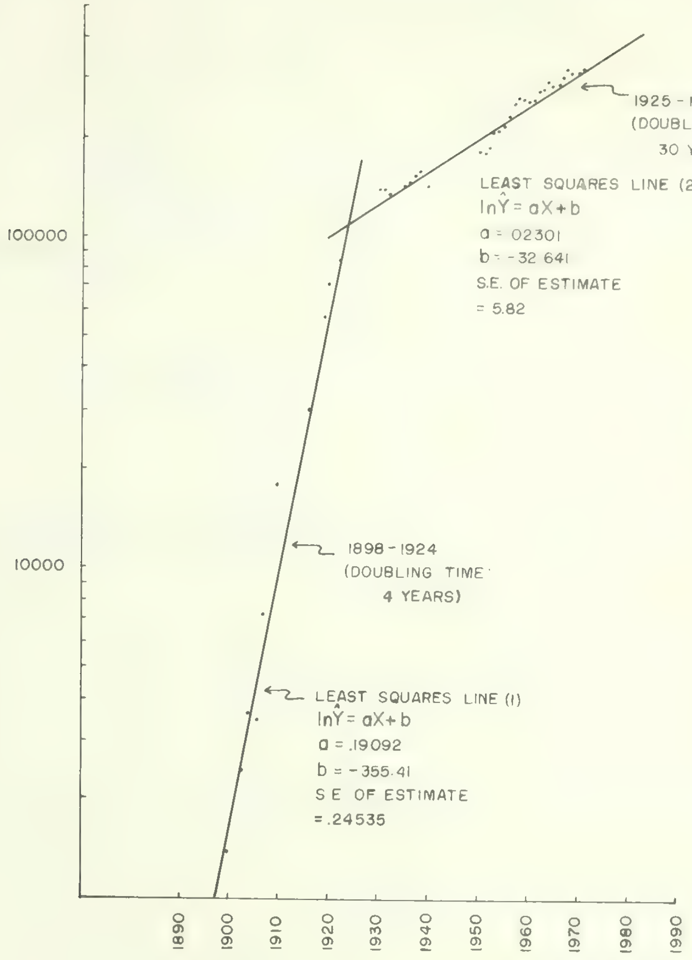
ANALYSIS OF THE GROWTH OF TWO CITIES

The understanding of past and present dynamic trends is required for successful urban planning if we are to make future growth more orderly and less chaotic, more useful to mankind and less wasteful of resources. Improving communication between disciplines that already make wide use of analytical tools and those just beginning to make use of such tools for solving problems of human settlement provided the impetus for a study. An attempt was made to collect data from the metropolitan areas of Oklahoma City and Tulsa, Oklahoma, which represent a 100-year time span (fig. 1). These data were the basis of an analysis and comparison of the growth trends in these two cities *(Normand 1975)*. The analysis technique used was that of regression of the data on time. Efforts to plot the data on a linear graph produced the usual poor fit to a straight line; however, when regression was performed on the log of the data, results represent familiar growth curves (fig. 2 and 3).

The analysis produced some interesting highlights of the characteristics of the two cities. For example, the consumption of electricity in Tulsa doubles every 8 years while the population has doubled only every 30 years since about 1922. The fact that Tulsa continues its use of electrical power at a rate almost four times faster than that of population growth points out a higher per-capita use of power at an ever-increasing rate. In both cities the population growth rate changed drastically in the 1920s. Tulsa's population doubled about every 4 years until 1922, then changed rate and has since doubled every 30 years. Oklahoma City's rate changed from a doubling time of 7 years to 30 years.

Such a change is attributed by some to oil boom years. However, the difference in character of the two cities is much better illustrated by graphs on economic indicators and employment. The highlights of population growth versus energy consumption illustrate a fast-approaching time when decisions will have to be made on proper resource allocation on a private and public scale.

Figure 1.—Population growth of Tulsa, Oklahoma. Regression of log Y on X.



This type of study could perhaps remove some barriers to interdisciplinary communication and utilization of analytical techniques in a practical application in metropolitan/environmental planning.

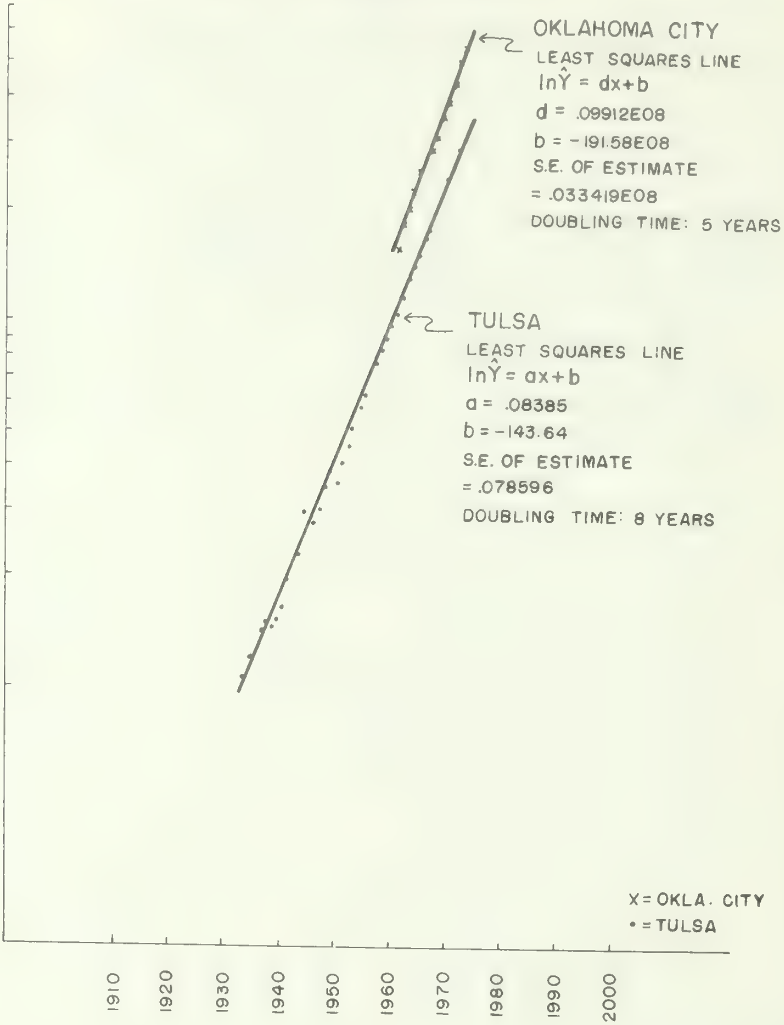
COMPUTER MOVIE OF THE GROWTH OF TULSA

In a text used by students of urban planning it is stated that "planners are ultimately interested in making statements about the relationships between key variables as they may or should exist at some future time. In order to make such statements, planners study the past and present conditions of the factors relevant to a given situation" (Goodman and Freund 1968).

Visualizing the evolution of the metabolism of a city is required in order to understand the character of its growth in the past and to plan for its future. With this idea in mind, data were collected from several metropolitan areas in Oklahoma for use in analysis of past and present trends, and for use in graphic presentation constructed by computer techniques.

One result of this project has been a computer movie of the growth of Tulsa *(Brady et al. 1975)*. In it are depicted the physical annexation process, from the original townsite to its present configuration. In addition, the demographic features are illustrated on linear graphs showing some of the dynamic

Figure 2.—Consumption of electricity (in millions of kilowatt hours) in Tulsa, Oklahoma. Regression of log Y on X.

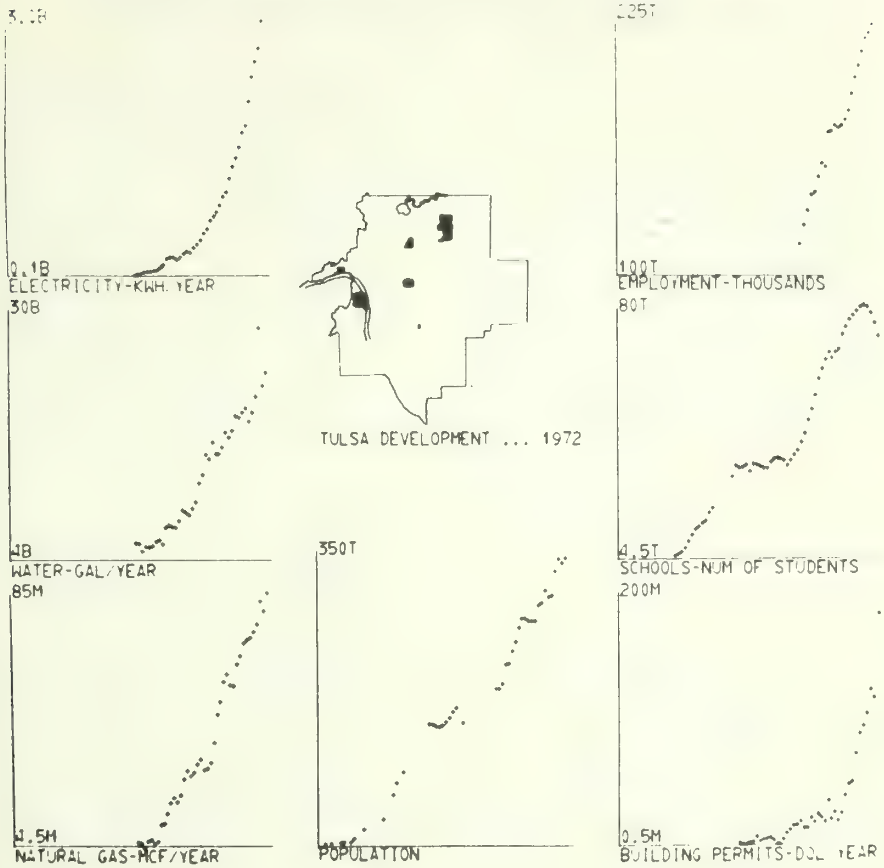


trends in this city: population growth, energy consumption, employment patterns, school enrollment, etc. (fig. 1 and 2). As a method for transferring techniques widely used in the scientific fields to that of planning for social needs, these computer graphic presentations have been found to be readily assimilable by the decision-maker as well as the ordinary citizen who has not had time to become algebraically oriented *(Eddy 1974)*.

FORECASTING DEMAND FROM PROPOSED DEVELOPMENTS

Evaluation of the impact of new developments in a community is anothe source of concern to urban decision-makers. Those agencies responsible fo approving zoning and platting of proposed developments, in particular, fin it necessary to make approvals for ne developments without the assurance tha public utilities and services such a water, sewers, and public schools wi

Figure 3.—Computer movie of the growth of Tulsa, Oklahoma.



be available to adequately serve those developments after completion. The environmental impact is also many times left in question. The Proposed Development Sub-File is designed to provide a relatively accurate and rapid computerized system of predicting the needs and impacts of such developments *(Tulsa City-County Health Department 1972)*. The ability of this system of comparative computer programs to accumulate the anticipated impacts of all proposed developments (from the early stage of zoning change to completion) is of great advantage. The data system will be of benefit to government agencies by aiding planning for utility expansions and school facilities and in assessing housing trends and availability of services.

Those who invest in such developments may also benefit from this project, as it will be capable of serving as an early warning system in predicting probable future difficulties with existing facilities in the earliest stages of planning, and, therefore, modification or delay of development before the financial commitment has been further expanded. The system will provide reasonably accurate estimates of the effect of all proposed developments and existing developments on sewage-treatment plants, water plants, sources of water, public schools, solid-waste-disposal facilities, and environmental quality. A sample of the output expected for presentation to the decision-making bodies is presented here (fig. 4) as well as the predicted

Figure 4.—Impact of a proposed development on services and utilities.

WATER TREATMENT CAPACITY ASSESSMENT

COUNTY: TULSA

FACILITY: TULSA MUNICIPAL SYSTEM	AVE	PEAK
EXISTING TREATMENT CAPACITY	100 000 000	136 000 000
EXISTING DEMAND	64 400 000	117 000 000
REMAINING CAPACITY	35 600 000	19 000 000
PLATTED COMMITMENT	2 880 000	4 320 000
REMAINING CAPACITY	32 720 000	14 680 000
PRESENT ZONING COMMITMENT	8 640 000	12 960 000
REMAINING CAPACITY	24 080 000	1 720 000
PROPOSED ZONING DEMANDS		
Z 4701 CS	10 500	15 750
Z 4702 CS	35 000	52 500
Z 4706 CG OL	5 890	8 835
Z 4707 CS	56 000	84 000
Z 4712 CS OL RM-1 RD RS-3	425 200	637 800
TOTAL ZONING DEMAND	532 590	798 885
REMAINING CAPACITY	23 547 410	921 115
FUTURE DESIGN CAPACITY	110 000 000	145 000 000
YEAR: 1978		

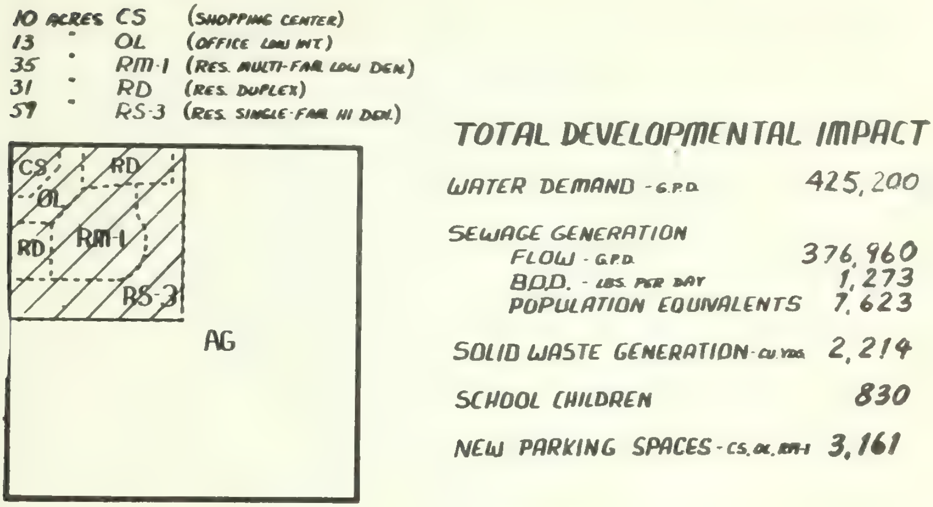
FACILITY: BROKEN ARROW PLANT

COUNTY: CREEK

WATER SOURCE ASSESSMENT

SOURCE: SPAVINAW	AVE	PEAK
RELIABLE YEILD	65 000 000	65 000 000
EXISTING DEMAND	64 400 000	117 000 000
REMAINING YEILD	600 000	-52 000 000
PLATTED COMMITMENT	2 880 000	4 320 000
OVERLOAD	-2 280 000	-47 680 000
PRESENT ZONING COMMITMENT	8 640 000	12 960 000
OVERLOAD	-10 920 000	-60 640 000
PROPOSED ZONING DEMANDS		
Z 4701 CS	10 500	15 750
Z 4702 CS	35 000	52 500
Z 4706 CG OL	5 890	8 835
Z 4707 CS	56 000	84 000
Z 4712 CS OL RM-1 RD RS-3	425 200	637 800
TOTAL ZONING DEMAND	532 590	798 885
OVERLOAD	-11 452 590	-61 438 800

Figure 5.—Sample output of proposed development system, showing assessment of demands on water treatment and water source.



10 ACRES	CS	(SHOPPING CENTER)
13 "	OL	(OFFICE LOW INT)
35 "	RM-1	(RES. MULTI-FAM. LOW DEN.)
31 "	RD	(RES. DUPLEX)
59 "	RS-3	(RES. SINGLE-FAM. HI DEN.)

TOTAL DEVELOPMENTAL IMPACT

WATER DEMAND - G.P.D.	425,200
SEWAGE GENERATION	
FLOW - G.P.D.	376,960
B.O.D. - LBS. PER DAY	1,273
POPULATION EQUIVALENTS	7,623
SOLID WASTE GENERATION - CU.YDS.	2,214
SCHOOL CHILDREN	830
NEW PARKING SPACES - CS.OL.RM-1	3,161

impact of a hypothetical development as it would be assessed by this system (fig. 5).

AIR-POLLUTION MODELS AND COMPUTER MOVIES

Several existing air-pollution models have been adapted to the air-quality conditions in the Tulsa area. An illustrative sample of the Climatological Dispersion Model *(Busse and Zimmerman 1973)* is presented here. An annual average of ground-level concentrations of pollutants from both point and area sources is obtained by using this model. By using the original program, receptor points can be located to pinpoint concentrations of two pollutants at a time.

In addition, program modifications have made it possible to map concentrations of pollutants at locations arranged n a grid of specified size, rather than ndividual receptor sites, as reported by Normand *(1975)*. The unit area of 1 quare mile was chosen to conform to the grid pattern of the major streets f Tulsa. The concentration estimate is made for receptors located at the center f these square-mile areas. A cross-section of the grid along a north-south column is shown here (fig. 6), for the effluent SO_2. This display of pollution concentration is an aid to visual perception of the dispersion of air pollution over a city-wide area. This method can be used by urban planners in assessing the impact of new industrial location on an annual basis.

Another model, which takes into account the differentiations in terrain of an urban area, as well as time and space variations in the wind field and stability of atmospheric conditions, is the Diffusion Wind Atmospheric Dispersion Model developed by Shannon *(1974)*. This is a four-dimensional model (X, Y, Z, T). The grid is vertically divided into eight layers, with a horizontal grid-mesh size of 1 square mile. Wind stability and effluents vary in space and time (fig. 7 and 8). A three-dimensional computer movie has been made *(Shannon 1974)* of the output of this model, showing a cloud of pollution moving across an urban area. The pollutants and stability are varied at 5-minute intervals.

This model permits the examination of the frequency distribution of various pollutants on different space-time scales.

Figure 6.—Cross-section of grid showing concentrations of SO_2 predicted by climatological dispersion model.

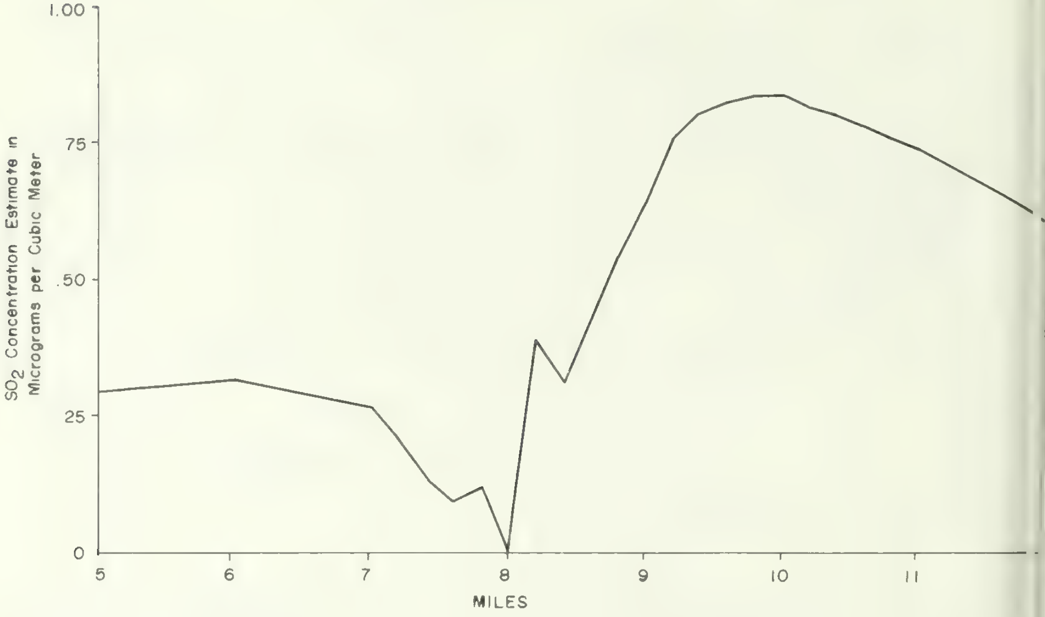
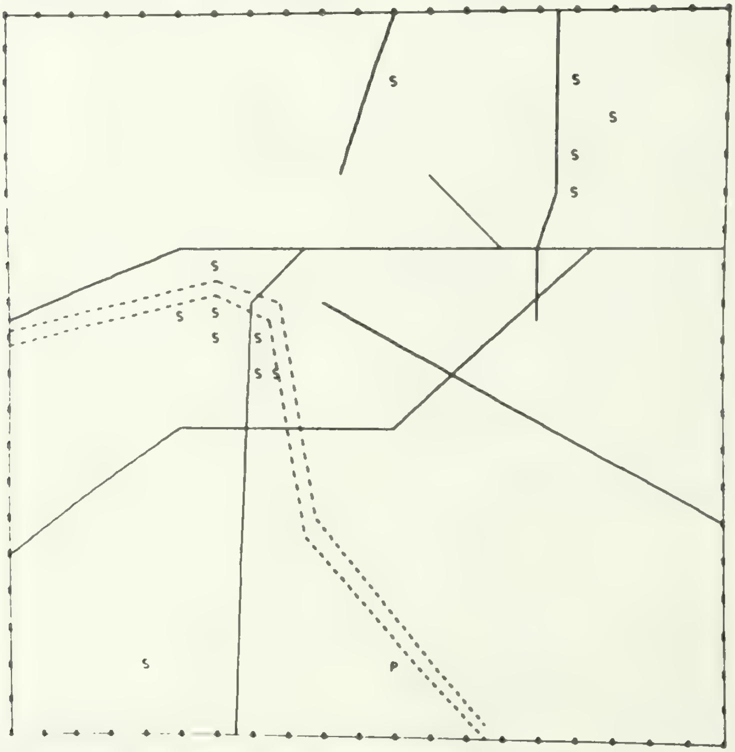
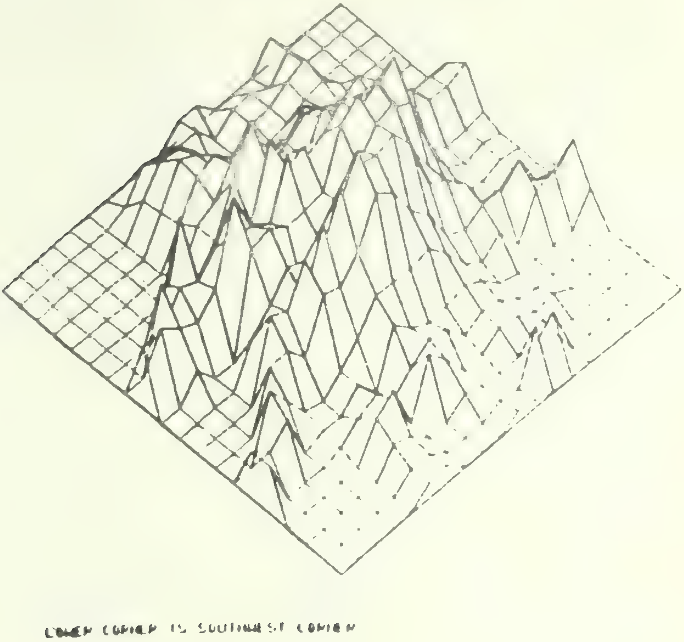


Figure 7.—Tulsa industrial point sources, future electrical generating plant site, freeways (output from diffusion wind atmospheric dispersion model).



TULSA INDUSTRIAL POINT SOURCES (S). FUTURE ELECTRICAL GENERATING PLANT SITE (P).
FREEWAYS (SOLID LINES). ARKANSAS RIVER (DASHED LINES)
GRID INTERVAL ONE MILE TOP IS NORTH

Figure 8.—Hydrocarbon emissions from current traffic (Kg./sq. mi./day).



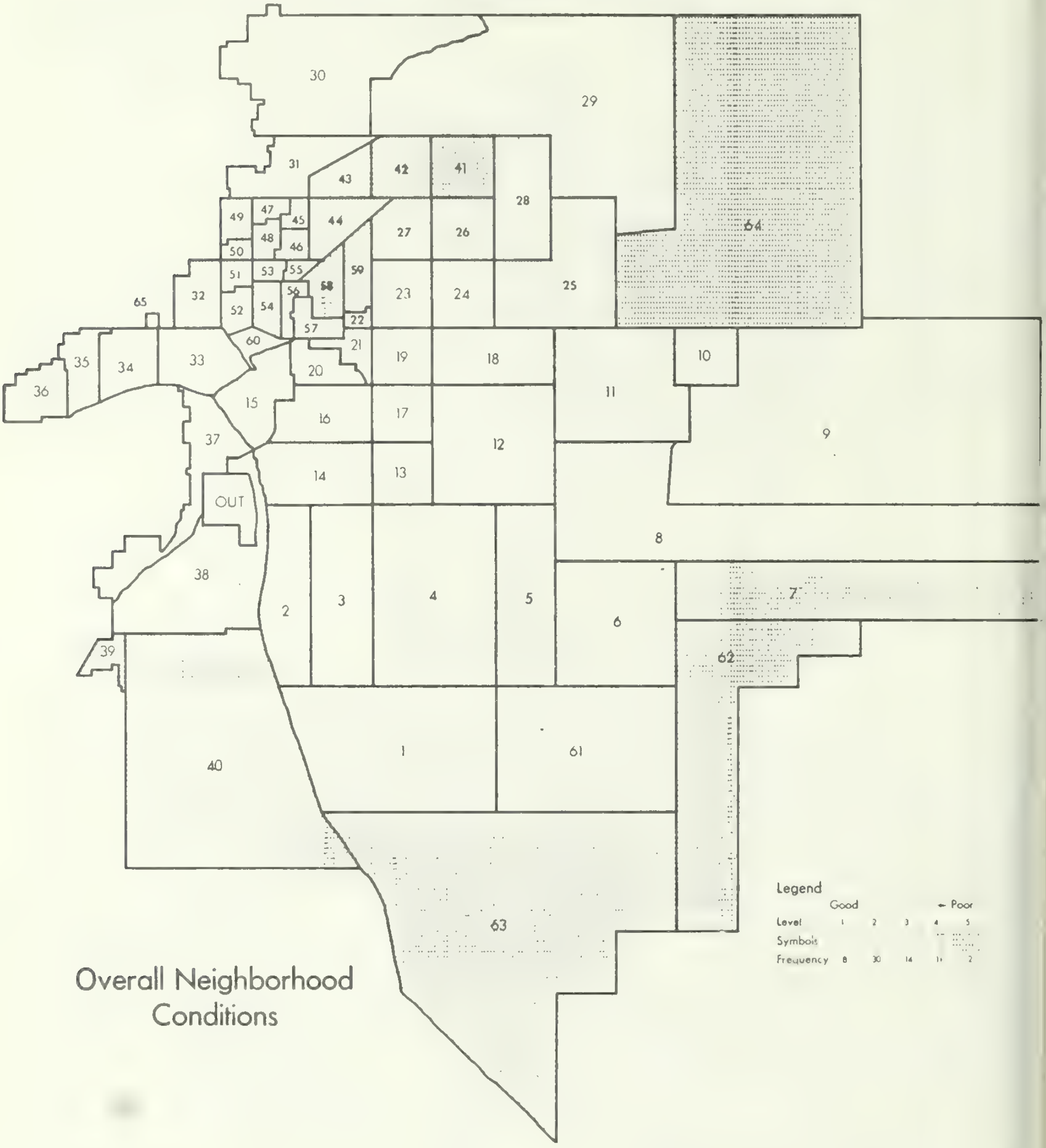
Optimal placement of monitoring sensors, as well as prediction of the impact of new industrial sites are two of the possible applications of this model for the planner of the metropolitan environment. Computer-produced movies of air-pollution patterns have proved very valuable for transferring large amounts of technical information in an easily assimilable format to nontechnical decision-makers in a short time.

ENVIRONMENTAL DEFICIENCIES VERSUS DEMOGRAPHIC CHARACTERISTICS OF A CITY

Evaluation of physical environmental deficiencies in relation to the characteristics of the population was the subject of another report. Data collected by the Tulsa City-County Health Department was selected for the study. Several computer programs that employed statistical techniques were used. Multiple linear regression and stepwise regression were used, and the relationships found are reported by Normand *(1974)*.

In a more extensive study by the Tulsa City-County Health Department, the whole area of Tulsa was surveyed, and many other variables were considered, employing the Neighborhood Environmental Evaluation Decision System (NEEDS), developed by the Bureau of Community Environmental Management of the Health Services and Mental Health Administration, U. S. Public Health Service. The statistical methods used in this survey were correlation analysis, factor analysis, cluster analysis, and regression analysis. An evaluation was made of complex combinations of interrelated conditions occuring in the living environment of specific areas of the community. Fig. 9 shows the ranking of overall neighborhood conditions, as one of the many variables analyzed. The net result of this study was to produce a statistically logical set of planning districts, each one of which

Figure 9.—Overall neighborhood conditions from NEEDS study in Tulsa, Oklahoma.



contained homogeneous attributes that distinguish it from its neighbors.

SUMMARY

Experts employed to solve the problems facing the metropolitan areas today are faced with dilemmas. One is the language barrier between different disciplines. The transfer of information and technology is the first obstacle to overcome. Some techniques of data assimilation that can be used to overcome th communication problem have been presented in this paper. An attempt ha been made to show some techniques employed now by the sciences, which coul be used to provide accurate and instantaneous presentations of consequence of past and possible future actions b the administrators of metropolita areas. The rapid pace at which chang occurs is highly visible in large urba concentrations. The technology is available to show alternative methods of resource allocation to accommodate changes, and it is hoped that this effort will provide encouragement to the planners of metropolitan environment to make use of such techniques.

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- Pennington, New Jersey.
- Princeton, West Virginia.
- Syracuse, New York, in cooperation with the State University of New York College of Environmental Sciences and Forestry at Syracuse University, Syracuse.
- Warren, Pennsylvania.

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WORKSHOP REPORT
on Acid Precipitation and the Forest Ecosystem

JAN 6 1977

USDA FOREST SERVICE GENERAL TECHNICAL REPORT NE-26
1976

NORTHEASTERN FOREST EXPERIMENT STATION
FOREST SERVICE, U.S. DEPARTMENT OF AGRICULTURE
6816 MARKET STREET, UPPER DARBY, PA. 19082

FOREWORD

This is a report on the workshop following the First International Symposium on Acid Precipitation and the Forest Ecosystem, held at The Ohio State University, Columbus, Ohio, on 15-16 May 1975. The findings and recommendations offered here are the consensus of Workshop participants and are not to be considered as official positions of the USDA Forest Service, The Ohio State University, or the National Science Foundation.

The Symposium and the Workshop were sponsored by the Northeastern Forest Experiment Station, USDA Forest Service; the Atmospheric Sciences Program of The Ohio State University; and the National Science Foundation, Grant No. DES 75-13749.

WORKSHOP REPORT on Acid Precipitation and the Forest Ecosystem

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INTRODUCTION

THE FIRST International Symposium on Acid Precipitation and the Forest Ecosystem provided the first world-wide forum devoted to consideration of acid precipitation and forestry problems. The Symposium brought together experts from diverse fields of the physical and biological sciences to discuss their research and their concerns about a potentially serious environmental problem. A Workshop, organized as a follow-up to the Symposium, benefited greatly from participation by more than 60 international scientists. This is a report on that Workshop.

Five discussion panels were formed to consider (1) Atmospheric Emissions, Transport, Transformation, and Removal; (2) Effects on Aquatic Systems; (3) Effects on Forest Soils; (4) Effects on Forest Vegetation; and (5) Energy-Related Issues. Two co-chairmen in each problem area were responsible for organizing, developing, and reporting the findings of their respective panels. Many of the panel members on energy-related issues also participated in other panels to bring still broader perspectives to the relationship between acid precipitation effects on the forest ecosystem and energy.

This report identifies the nature, extent and dimensions of the problems associated with acid precipitation. The recommendations contained here should serve as a guide for research by scientists and for program-planning by academic, industrial, government, and public-interest groups.

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ACID PRECIPITATION: AN ENERGY-RELATED ENVIRONMENTAL PROBLEM

THE ENERGY PROBLEMS of the world relate to nearly every aspect of life. Of great importance is whether we have or are developing the knowledge needed to deal with these problems in the most efficient, economic, and environmentally beneficial ways. The effects of acid precipitation on the earth's ecosystem are areas worth immediate attention.

The relationship of acid precipitation to energy production from fossil fuels is complex (fig. 1). Further, there are significant unanswered questions about the ecosystem and its ability to regenerate resources such as agricultural crops and forest vegetation under the stress of acid precipitation.

In Sweden and Norway the acidity of rain and snowfall has increased to the point that some streams and lakes have become toxic to fish and other organisms. Further studies have suggested that forest growth in these countries has been adversely affected. The higher acidity is associated primarily with the sulfate and nitrate contents of the precipitation in Scandinavia. The sources of these compounds appear to be mostly anthropogenic and have been traced to sites as remote as 2,000 kilometers. This kind of observation has caused concern in areas of the world that are generally downwind from heavily urbanized and industrialized regions. Potentially impacted areas include the eastern United States and Canada and portions of the southwestern United States.

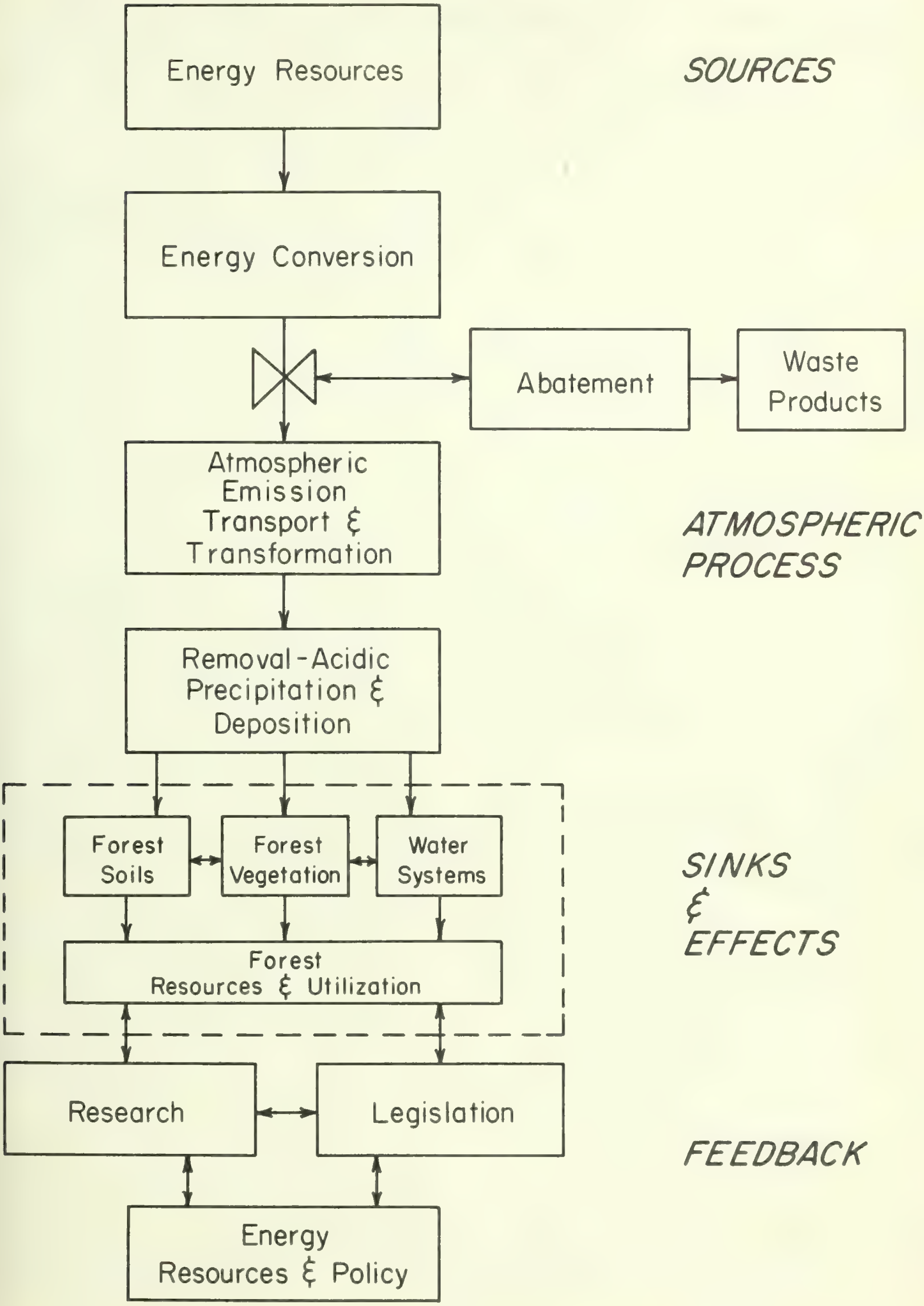
Oxides of sulfur are produced by the oxidation of sulfur contained in fuels and ores when they are combusted or smelted. The higher the sulfur content, the greater the amount of sulfur oxides emitted into the atmosphere. Major producers of sulfur oxides are power plants (both public utilities and those that provide energy for various industries); copper, lead, and zinc smelters; steel plants; and urban areas where coal and fuel oil and sulfur-containing gas are used for space heating. Automobiles may also be a source of sulfur oxides, but their contribution, except perhaps in urban regions, is relatively minor compared to that of industrial processes. Natural sources of important sulfur-bearing compounds include volcanoes, fresh and salt waters, and biological reactions.

Oxides of nitrogen are formed during combustion at high temperatures. Significant sources of NO_x are power plants, automobile exhaust, smelting operations, and space heating. However, the estimate of natural vs. anthropogenic emissions is overwhelmingly toward natural sources, which are primarily due to biological reactions.

Acidifying materials emitted into the atmosphere are subjected to many conditions. When they and other potentially harmful or beneficial compounds are removed from the atmosphere, the forest ecosystem may be affected. Because of this relationship and the possible importance and future implication of acid precipitation on the forest environment, the First International Symposium on Acid Precipitation and the Forest Ecosystem was held in May 1975 at The Ohio State University to assess present knowledge on the subject.

This report presents the findings of a Workshop that was held following the Symposium. The major Workshop recommendations were that (1) more research is needed to evaluate ecological effects and economic impact of changes in the acidity and other chemical properties of precipitation and (2) a network should be established to monitor the chemistry of air and precipitation in rural and urban locations throughout the world.

Figure 1.—The relationship of energy production to acid precipitation.



ATMOSPHERIC EMISSIONS, TRANSPORT, TRANSFORMATION, AND REMOVAL

The increasing acidification of precipitation has added a new dimension to the air-pollution problem — pollution that had been treated largely as a local problem has become a regional one. Also, because of the long-range transport attributed to acidic pollutants, acid precipitation must be considered an international environmental problem.

To determine acid input to the forest ecosystem, a thorough understanding of emissions, chemical and physical transformations, transport, and removal mechanisms is required. Pollutants of various kinds are emitted from both natural and anthropogenic sources. While the emissions are often complex in their chemical makeup, those of greatest concern are SO_2, CO, NO_x, reactive (nonmethane) hydrocarbons (RHC) and particulates. The particulates range from organic to inorganic, from toxic to nontoxic, and over a few orders of magnitude in size. Of greatest concern are the smaller particulates in the size range from 0.3 μm to 3 μm; in addition, chemically toxic particulates such as heavy metals of various sizes may also be important.

While in the atmosphere, air pollutants may react with each other and with natural components of the atmosphere such as water vapor, ammonia, ozone, and other hydrocarbons. Simultaneously, these pollutants are transported by atmospheric motions both horizontally and, to a lesser extent, vertically. Finally, they are removed either by physical encounter with surfaces (dry deposition) or by precipitation (wet removal).

An understanding of atmospheric processes is essential in understanding their role in acid-precipitation-related problems. Furthermore, since the problems are more regional than local, the considerable amount of research on air pollution that has been aimed primarily at local phenomena is not adequate. Further research is required so that the extent to which anthropogenic emissions contribute to acid precipitation can be assessed.

Research Recommendations

I. Emissions

There is an insufficient amount of data on low concentrations (background) of air pollutants. This kind of data is particularly lacking for rural areas, but also is insufficient for locations where the air quality is considered good. Yet, evidence has been accumulating that pollution from industrial and urbanized regions is not necessarily all removed from the atmosphere in the vicinity of the sources, but is often transformed and transported up to thousands of kilometers away. Consequently, data collection must be improved and expanded to monitor low concentrations of pollution in general and acid precipitation in particular.

A. Improve and expand emission inventories of natural and anthropogenic sources of pollutants contributing to acid precipitation and related problems. These inventories should include SO_2, CO, NO_x RHC, and particulates. It is especially desirable to quantify the natural emissions of ammonia, H_2S, and other possible sources of acidity in the atmosphere. Spatial resolution should be at least of the same scale as anthropogenic emissions. Data should be sufficient to define seasonal averages.

B. Both national and international cooperation and standardization are necessary for the exchange of data on emissions and the long-range transport of pollutants. Industry should be encouraged to report on its emissions on a worldwide basis and make its data available to responsible scientific organizations.

II. Transport

Pollutants introduced into the air tend to follow atmospheric motions. This transport is mostly turbulent, exhibiting a distribution of energy over a wide range of scales. At the microscale, in the immediate vicinity of the source, emissions are diluted by four to six orders of magnitude. The remaining concentrations are spread over greater distances. Dispersion of pollutants to regional scales (hundreds of kilometers) seems to be responsible for observations of pollution remote from the sources. Since the atmosphere is in constant motion, once substances enter the atmosphere they can, if not removed, contribute to the global background. Because of the large scales, long time factors, and relatively low concentrations of pollutants, new research efforts will be needed.

A. Establish national and international programs to monitor low concentrations of pollution and acid precipitation in particular.

  - Monitoring networks should have adequate resolution over regional scales.
  - Monitoring should be long-term and use standardized methods.
  - Networks should be established where substantial acidic precipitation exists and where the potential for future degradation is greatest.
  - Measurements should include pH, $[H^+]$, SO_2, NO_x, NH_3, $SO_4^=$ Mg, Cl, and acidity of particulates.
  - Precipitation chemistry should resolve the strong and weak acid contributions.
  - National and international systems of collection and dissemination of data should be established; priority should be given to establishment of a computerized data library for rapid analysis and retrieval.
  - Existing institutions such as the land-grant universities, Agricultural Research Service, and USDA Forest Service in the United States should be encouraged to lead the effort in data collection and analysis.

B. Long-range transport models should be developed. These are needed to trace the sources of pollutants and to test theories of transport, transformation, and removal by comparing model results with measurements from monitoring networks. Such models would be useful for predicting future trends in the condition and behavior of the atmosphere.

C. Meterological boundary-layer studies near major pollutant sources and over complex terrain are required. These will provide information on vertical mixing and identify any limitations of the mechanisms used in transport models.

III. Transformations

Atmospheric reactions and chemical kinetics play an important role in the transformation of anthropogenic emissions into acidifying substances. Of particular importance are the rates of conversion of sulfur dioxide to sulfur trioxide, sulfuric acid, and other possible sulfate aerosol precursors. Both gas phase and heterogeneous reactions involving sulfur dioxide and its derivatives and other acidifying emissions such as nitrogen oxides must be evaluated. More research is required to clarify the chemistry operating in the atmosphere, especially that involving sulfur, nitrogen, and chlorine reactants: the role of water vapor, ammonia, and other organic compounds should also be determined.

A. The nature of equilibria between natural raindrops and low concentrations of SO_x and NO_x and the effects of catalysts on the system should receive attention.

B. Laboratory-chamber experiments to study chemical reaction mechanisms generating acid substances under conditions with realistic atmospheric admixtures and realistic ambient concentrations of pollutant species should be performed.

C. Field investigations of the chemistry operating within plumes from individual sources and from multiple source regions should be expanded.

D. Field investigations of the atmospheric chemistry in rural regions should be made and evaluated in terms of known reaction kinetics, transport, and removal mechanisms.

IV. Removal Mechanisms

Removal of pollutants occurs in either dry or wet form. Dry removal results from impaction of the pollutants onto a surface and its retention there. Precipitation involves the water cycle of the atmosphere, in which absorption into hydrometeors occurs either through in-cloud rainout and snowout or through below-cloud washout processes. Understanding these removal mechanisms is essential to determining input to forest ecosystems. Research should help ascertain what the lifetime of pollutants is in the atmosphere, where they are likely to be deposited, and in what form they will be when deposited.

A. Develop techniques for determining the deposition of pollutants over large areas.
B. Perform laboratory and field studies of the aerodynamic processes of the dry removal of gaseous and particulate pollutants in forests. Both the injurious and possible beneficial results of the forest biomass as a pollution sink should be investigated.
C. Evaluate the effectiveness of cloud systems in the removal and redistribution of pollutants.
D. Develop and test theoretical and empirical relations that provide quantitative information about removal processes, including all precipitation phenomena. Results should be applicable to conceptual models relating to effects of atmospheric acidity.

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EFFECTS ON AQUATIC SYSTEMS

An important consequence of acid precipitation falling on the landscape is the acidification of lakes, ponds, and streams. Hundreds, possibly thousands, of lakes and streams in Sweden, Norway, southeastern Canada, and the northeastern United States have become so acid that dramatic changes in water habitats have been observed. For example, large areas of western, southern, and eastern Norway have experienced losses to salmon fisheries that amount to tens of millions of dollars annually. Studies in the United States indicate that fish populations have been adversely affected in 75 percent of the high-elevation lakes of the Adirondack Mountains of New York State and that many lakes and streams can no longer support salmanoid fishes.

In Canada near Sudbury, Ontario, where more than 3 percent of the world's estimated anthropogenic sulfur emissions are released into the atmosphere, acidification of nearby lakes has resulted, followed by the extinction of many fish and insect species and loss of algal populations. Adverse effects of the strong acids (sulfuric, nitric, and hydrochloric) in precipitation on bacteria, phytoplankton, zooplankton, macrophytes, invertebrates, and salamanders have also been observed in many watersheds.

Since acquatic habitats appear to be highly sensitive to acid precipitation and other atmospherically derived substances, research programs are required to further determine related aquatic system responses. These programs are particularly important wherever precipitation monitoring indicates the presence of strong acids and where the probability of possible future contamination is high.

Research Recommendations

I. Conduct a literature search on the effects of H^+ on aquatic organisms.

A literature search on the effects of H^+ on aquatic ecosystems is essential. This search should precede any investigations and should also be done as a continuing endeavor to keep abreast of current research accomplishments.

II. Establish permanent networks for monitoring precipitation chemistry.

To appraise the impact of acid precipitation on aquatic systems, the input to the system must be known. Concentrations of acids, bases, heavy metals, nutrients, organic solvents, and particulate matter should be determined in daily, seasonal, and yearly amounts. A standardized network of precipitation monitoring stations should be established throughout the world. Regional networks should be located in parts of the world where acid precipitation exists and where the potential for future acidification is most likely. Local monitoring near major sources is also required. In addition, several stations should be established in relatively isolated locations to provide reference data.

The following components may be present in precipitation and should be measured at least once a month: H^+, Ca, Mg, K, Na, SO_4, NO_3, Cl, specific conductance, total P, NH_4, alkalinity, titratable acidity, total organic carbon. Other useful measurements might include: Al, Fe, Si, Mn, Zn, Cr, Pb, Cd, Cu, Ni, Hg, PO_4, O_2, total N, color, particulates.

III. Develop criteria and establish permanent networks for monitoring volume discharges, chemistry, and biology of freshwater systems.

Surveillance of lakes and streams is essential for detecting changes in the aquatic life of these water bodies. For areas presently or potentially subjected to acid precipitation, representative lakes and streams (particularly those with low buffering capacity) should be established to monitor the following parameters:

A. Water volume discharge — continuous measurement or measurements sufficient to characterize water flows throughout the year.

B. Water chemistry — measurements in lakes should be made about 5 to 10 times yearly and during periods of limnological change. Streams should be monitored during their critical periods. Measurements should include: H^+, Ca, Mg, Na, K, NO_3, SO_4, Cl, specific conductance, color, temperature, O_2, total organic C, total P, total N, NH_4–N, alkalinity, acidity, Al, Mn, Zn. Measurements of Fe, Si, Cr, Pb, Cd, Cu, Ni, Hg, and PO_4–P might also be useful.

C. Water biology — documentation should include assessments of the following aquatic life:

Lakes—Phytoplankton, zooplankton, zoobenthos, and bacteria/fungi should be monitored four times annually. Macrophytes and fish should be monitored annually.

Streams — Epibenthic algae, invertebrates, fish, and bacteria/fungi should all be monitored annually.

IV. Conduct in-depth studies involving the hydrological, chemical, and biological interrelationships of aquatic systems with respect to small and large accretions of acids, heavy metals, and nutrient ions in acid precipitation.

Studies must determine the nature and extent to which aquatic organisms can tolerate and respond to high concentrations of added substances such as H^+ ions, heavy metals, and other materials that enter the ecosystem in acid precipitation. Examples of the kinds of studies recommended are given below:

A. The effects of acidification and toxicity on cell metabolism, reproduction, and life cycles of aquatic organisms. Among the most important of these are the microflora, phytoplankton, zooplankton, benthos, and nekton.

B. Interactions of acids, metals, and other chemicals with the aquatic system. These should include studies of chronic and acute toxicity, combined reactions, and secondary effects on organisms.

C. The influence of acidification on organism succession.

D. Genetic changes and the extent of short- and long-term species adaption to increases in acidity.

E. Ecosystem mechanisms, natural sources, processes, and limitations in lakes and streams for detoxification and degradation of strong acids, organic acids, heavy metals, and other substances.

F. Effects of acidification on physical aspects of water quality. Such studies should include stream and lake interaction with bottom materials, sediments, suspended particulate matter, translocation of nutrients adsorbed to the suspended particles, changes in light and temperature levels in varied strata of lakes or position in stream locations, content of dissolved oxygen, and conditions favoring fluctuations or stability in oxidation-reduction potentials.

G. Influence of heavy metals and strong acids on aquatic chemistry: solubility constants relative to other ions present in the system; storage and recycling of nutrients in stream and lake sediment.

V. Establish study sites for experimental research on watersheds that involve lakes and streams.

Representative ecosystems, involving lakes and streams and their watersheds, should be set aside for studying the effects of acid precipitation. These systems should range from oligitrophic to near eutrophic bodies of water and from very fragile systems to those well buffered. Research should involve:

A. Integrated approaches for studying whole watersheds. In-depth investigations should be conducted on the interrelationships of nutrient status, acid media, and heavy metals on aquatic life and their distribution and physiological changes, including adaptations to changes in other organisms. Changes in microbial processes, influence of sulfur and nitrogen loadings and transformations, and effects of nutrient cycling within all portions of the ecosystem should be examined as well. Natural undisturbed ecosystems should be compared with artificially manipulated systems as exemplified by the Freshwater Institute, Winnipeg, Canada, in the Experimental Lakes Area (ELA). Effects of short- and long-term nutrient flushing from watersheds to lakes and streams should be included.

B. Experiments to determine possible ways of ameliorating any changes in the chemical and physical characteristics of lakes and streams to some acceptable biological state.

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EFFECTS ON FOREST SOILS

The effects of acid precipitation on soil re best considered together with the vegeation it supports because of the many recipocal relationships that occur among soil, lant, and aquatic systems. The biotic-soil ystem constitutes the fundamental interface etween the atmosphere and the geologic ubstratum. In broad terms, this interface erves to transport solar energy via internediates of photosynthesis and ramifications f the plant root system to the surface of rimary minerals in the substratum. Here atent chemical energy of previous eras is ctivated and added to the total energy suply of the system, and in the process nutrient ons are released to further sustain growth f producer and consumer organisms of all ypes, particularly those related to the soil.

The effects of acid precipitation will be nuch greater in some ecosystems than in thers. Three primary relationships exist etween acid precipitation and the buffering bility of the ecosystem. First, when acid recipitation falls on an ecosystem in which he total capacity of the plants and the soil n which they are growing cannot supply ufficient quantities of basic cations to signiicantly alter precipitation characteristics, he drainage waters leaving that system will e controlled by the degree of acidity in the recipitation that falls on it. In this case, hanges in atmospheric chemistry caused by ollution may be reflected in drainage water hemistry. This ecosystem would experience eterioration of the marginal plant cover, which in turn could lead to further reduction n productive capacity due to soil erosion.

In the second case, when the total buffer capacity of the ecosystem is in approximate balance with the input of acidity from the atmosphere, the productive capacity of the ecosystem will probably sustain itself, and drainage water chemistry will reflect the functioning of the ecosystem rather than the composition of incoming precipitation. However, if further stresses are superimposed on the system, then the buffer capacity may be exceeded, resulting in changes in drainage water characteristics and the ultimate self-sustaining capabilities of the system.

In the third relationship, the buffer capacity of the system far exceeds the acidity added in precipitation. Even if additional disturbances are introduced, recovery would be expected to proceed normally because of the inherent productive capacity of the soil. A more complete understanding of how the natural plant-soil ecosystem functions with and without precipitation pollutants is needed. With respect to soil acidification, are soils acidified by atmospheric pollutants; where does acidification occur; what mechanisms are involved; and what ecosystem components are most affected? Additional research on these and related topics is required to assess the potential impact of acid precipitation on forest soils.

Research Recommendations

I. Establish a network of representative research areas on a global scale to provide baseline data on soil processes both within and external to regions of significant acid precipitation. In addition to such areas, all on-going forest ecosystem research projects are encouraged to include study of acid precipitation.

II. Study effects of acid precipitation on biological processes that affect the soil.

The biotic-soil interface constitutes an extremely complex system, which requires better understanding. A self-acidifying process generally occurs. Organic matter originating in the canopy and dead roots within the soil undergo decomposition in which complex molecules are gradually hydrolized by consumer organisms to constituent compounds and elements. Consumer organisms include microfauna, macrofauna, and microflora. The system is generally saturated with CO_2 and contains organic acids of various types. In addition, microbial oxidation of organic nitrogen to nitrate and organic sulfur to sulfate increases hydrogen ion activity, usually resulting in a lower soil pH. As development of the system progresses, the number of species involved at each trophic level tends to increase, and utilization of all resources becomes more complete. To improve our understanding of this complex system studies should concentrate on:

A. Organic matter decomposition — this should include relationship with and effects on nutrient mineralization and immobilization, particularly with respect to nitrogen, sulfur, and phosphorus; food-web relationships between the soil invertebrate community, soil microorganisms, and bird and animal predators; and the negative and positive selective processes of acid precipitation on decomposer organisms.
B. Nitrogen fixation and volatilization.
C. Soil respiration.
D. Rhizosphere effects and plant root responses.
E. Mycorrhiza.

III. Investigate the effects of mineral weathering and clay development.

The nature and composition of minerals in the substratum are important in determining the rate of clay formation and the type of clay minerals present in the soil. Clay minerals, whether they are of primary or secondary origin, together with organic matter, constitute the colloidal surfaces that regulate behavior and ionic composition of the soil solution, thus influencing soil acidity, nutrient availability to plant roots, and their associated microorganisms and nutrient losses from the soil system, all of which are related to the general buffering capacity of the soil as well as to soil productivity. It is this general buffering capacity that determines the susceptibility of a natural biotic-soil ecosystem to acid precipitation. Research on this should include studies on:

A. Solution equilibria and nutrient loss.
B. Clay mineral formation and alteration of characteristic patterns.
C. Organic matter-clay complexes.
D. Soil physical properties.

IV. Conduct in-depth studies on how acid precipitation affects soil chemical processes.

Since soil chemistry determines to a great extent availability of nutrients as well as possible undesirable elements and compounds to plants, the influence of acid precipitation on soil chemistry should be well understood. Studies are needed in the areas of:

A. pH measurements and soil reactions, particularly oxidation-reduction mechanisms.
B. Hydrogen-ion exchange equilibria with other cations.
C. Micronutrient and heavy metal sorption and release and complex formation.
D. Anion sorption.
E. Direct sorption of atmospheric sulfur dioxide.

V. Examine effects of acid precipitation on nutrient availablity and plant growth.

The effects of soil changes, resulting from acid precipitation, on plants is treated in Section 5 on Effects of Acid Precipitation on Plants. Nevertheless, soils scientists should pursue research on:

A. Species sensitivity to variations in soil acidity and other related changes.
B. Changes in plant succession in different soil systems.

VI. Identify and classify soil systems according to their susceptibility to damage from acid precipitation.

Studies should identify regions that are most likely to be affected and to what extent damage might occur. Research should emphasize:

A. Short- and long-term effects.
B. Damage threshold values.
C. Relationships to other cultural practices and influences, including silvicultural management, species selection, site preparation, fertilization, and fire.

VII. Develop and test ameliorative measures to reduce the impact of acid precipitation on soil systems.

Accommodation procedures such as liming or introduction of new plant species should be investigated along with an examination of any concommitant benefits and injury.

VIII. Develop computer simulation models for:

A. Predicting long-term effects of low-level inputs of acidity on soil characteristics and ecosystem productivity.
B. Predicting long-term effects of ameliorative measures.
C. Identifying sensitive soil factors and processes.
D. Establishing priorities for critical research needs.

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EFFECTS ON FOREST VEGETATION

Vegetation covers most of the land surface-area of the earth. Thus, the surfaces of leaves and stems are the initial deposition sites for airborne matter of all kinds. In a mature forest, an average raindrop will be intercepted by three tiers of foliage before it reaches the soil.

Acidic precipitation, therefore, can affect vegetation both through direct contact with external plant surfaces and through root interactions in the soil.

Acidic and other substances in the atmosphere cause a variety of demonstrated effects on vegetation. A most striking example has been the submarine encroachment of peat moss (Sphagnum spp.) into lakes and streams subjected to acidic precipitation in Sweden. Analyses of forest growth in southern Sweden from 1896 to 1965 show a 2 to 7 percent (average 4 percent) decrease in growth between 1950 and 1965; scientists have attributed this to acidification. Several attempts to quantify similar responses from acidification on forests in the United States have been inconclusive.

Among many reported direct effects of natural and simulated acidified rain on vegetation are: alterations in cuticular features such as stomata size and frequency, which are related to acidity; increased bark acidity; changes in the physiology of foliar organs; alteration in root functions; direct injury to the foliage of conifer and deciduous trees; poorer germination of seeds; accelerated leaching of nutrients from foliage; increased leaching of plant nutrients from humus; inhibition or stimulation of plant diseases; and inhibition of nitrogen-fixing bacteria in herbaceous crops.

Much greater knowledge of the injurious and beneficial effects of acid precipitation and other atmospheric substances on vegetation is essential. Research is required on a broad front and should include effects on forest growth, regeneration, reproduction, and related factors needed to maintain ecological stability.

Research Recommendations

Initial emphasis in research should be aimed at identification of specific organs, species or types of plants, physiological processes, or biological interactions that are influenced by acidic precipitation. These tests should be made with individual plants or simple symbiotic relationships and simple soil systems. These initial efforts should focus on processes that are most likely to be affected by acidic precipitation such as: erosion of cuticular waxes, activity of bacterial symbionts, or growth of plants in soils with low buffering or base exchange capacity.

Concurrently, monitoring networks should be established to measure changes in the chemistry of precipitation on a continuous and long-term basis. Surveys should be conducted to identify regions and types of vegetation that are most likely to be affected by acidic precipitation. As the monitoring networks bcome functional, attempts should be made to correlate effects observed in the surveys with rainfall parameters. This effort should be integrated with other forest, agricultural, hydrological, and geological surveys. Specific research needs follow:

I. Establish permanent networks to monitor the chemistry of air and precipitation throughout the world.

Monitoring networks are required to quantify potentially injurious substances and beneficial nutrient elements deposited from the atmosphere into agricultural, forested, and aquatic sites. These networks should be designed with the following criteria:

A. Standardized collection and analytical methods.

B. Long-term monitoring in both rural and urban regions.

C. Analyses of air, dry deposition and precipitation samples to include: NO_2, NO_3, PO_4, total P, K, Ca, Mg, SO_3, SO_4, Mn, Zn, Cu, Fe, Mo, SiO_4, Al, Na, Cl, Pb, Ni, pH, total acidity, free acidity, and organic acids.

Integration with established studies such as those developed in the International Biological Program, the Man in the Biosphere Program, and research watersheds maintained and operated throughout the world.

I. Perform controlled experiments with simulated rain.

Controlled experiments are needed to easure responses of vegetation to natural nd simulated rains in order to identify and etermine the impact of acidity. Care should e taken to note chemical and physical proprties of these rains. Experiments in growth ambers, controlled environmental facilities, nd greenhouses on individual plant and imple soil systems can simulate elementary cosystems. Field chambers with communies of plants can simulate more complex cosystems. Plant effects of particular imortance may be:

Injury—measured by suitable percentage scales.
Growth—measured as leaf area, plant height, yield, total biomass.
Reproduction—both direct effects on reproductive systems and possible genetic effects.
Physiology—photosynthesis, respiration, nutrient uptake.
Biochemistry—pool changes, enzymes affected, energy relations.
Interactions and predisposition—air pollutants, pathogens, insects, other environmental stress factors.
Other effects—changes in associated flora (lichens, mosses, phyllosphere, and rhizosphere organisms), erosion of cuticular leaf surfaces, development of plant organs, animal browsing preferences.

II. Investigate ecological processes.

Effects of precipitation on vegetation must ccount for influences of supporting soils and ater. Therefore studies of these ecological rocesses are necessary to determine the mpact of acidity on plants in their total nvironment.

Nutrient cycling—including leaching of nutrients from plants and soil.
B. Base-exchange capacity of soils — displacement of cations by hydronium ions.
C. Nitrogen fixation—by blue-green algae, symbiotic and free living bacteria, simple ecosystems.
D. Nutrient uptake—effects on anion and cation uptake by roots.
E. Rhizosphere relationships — effects on microflora and microfauna of the rhizosphere.
F. Formation and function of mycorrhizae.
G. Species and genetic diversity in natural forests and grasslands.
H. Soil-plant-animal interrelationships — study both simple and complex associations.
I. Ecosystem stability — changes in the density and diversity of plant and animal species over time.

IV. Develop computer models for predicting ecosystem changes.

If significant alterations in vegetation are detected, computer modeling could provide important information on potential long-term effects that might occur. Such studies might also improve our understanding of how a complex forest ecosystem works. Furthermore, these models might be useful for testing such proposed remedial actions as:

- Liming of soil to neutralize excess acidity and determine costs and benefits.
- Development of acid-tolerant varieties of economic plants.
- Development and enforcement of air-quality standards for emission and/or ambient concentrations of acidifying substances.

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ENERGY-RELATED ISSUES

The world is presently facing serious prob-
ms deciding environmental tradeoffs for the
ke of energy production at the least im-
ediate economic cost. The relationship be-
een acid precipitation and energy-related
sues has been discussed previously in Sec-
on 1. Furthermore, many other major is-
es in the world may affect or be affected by
id precipitation; e.g., health, fuels policy,
r quality and standards, shortages of natu-
l resources, critical energy needs, inter-
tional affairs, environmental tradeoffs,
nd-use policy, water quality, and transpor-
tion may all be related in one way or
other. It is clear that the acid precipita-
on-energy relationship raises many ques-
ons that need to be answered.

esearch Recommendations

Since acid precipitation may produce ser-
us consequences in the forest ecosystem and
ssibly elsewhere, methods for decreasing
is acidity must be found. Advances are
cessary in many areas, including:

Reduce acid-forming emissions from com-
bustion of present fuels.

Numerous programs are under way to de-
lop economic methods for removing sulfur
ides and related atmospheric pollutants
om emissions. These efforts should con-
ue to be pursued vigorously. In addition,
ograms aimed at removing sulfur from
els prior to combustion should be expanded.
onomic incentives are needed to increase
ese efforts and to develop use for waste
aterials that result from fuel cleansing and
ack emissions.

. Develop alternate sources of energy.

. Alternative energy sources for fossil fuels that do not introduce acidifying substances into the atmosphere and do not pose equal or greater environmental hazards are greatly needed. The environmental impact of non-acidifying energy sources such as solar, wind, nuclear, hydrological, and ocean currents and waves and thermal gradients require careful analysis and comparison with the impact of fossil fuels. When environmental impact assessments are made for other possible sources of energy such as geothermal and ocean tides, an examination should be made of their possible contributions to acidic precipitation.

B. Research and economic analyses on vegetation utilization as fuels should be accelerated. Vegetation is also a significant energy resource that is produced through biological processes that utilize solar energy. Plants provide us with supplementary heat energy and may ultimately be an important source of liquid and gaseous fuels.

III. Clarify the relationship between sources of acidic pollutants and forest sinks.

Forests are a major sink for atmospheric pollutants. Their role in cleansing the atmosphere should be thoroughly investigated for both wet and dry removal and for possible utilization of atmospheric trace substances as beneficial nutrients. An understanding of these potentially ameliorative processes along with injurious responses is required for establishing air-quality standards for major sources of acid precipitation.

IV. Identify primary sources of acidic pollutants in the atmosphere throughout the world.

In order to determine regions where acid precipitation may be a potential problem, an inventory of major natural and anthropogenic sources of acidifying substances in the atmosphere is required. This inventory should be combined with model studies of atmospheric transformations and transport and with an evaluation of susceptibility of various ecosystems to increasing acidity. Results of such studies may be important for establishing future land-use practices.

V. Perform studies relating to optimum utilization of energy resources, including acid precipitation as a major environmental threat.

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AN OVERVIEW OF THE EIGHTH ANNUAL NORTHEASTERN FOREST INSECT WORK CONFERENCE

by THOMAS ODELL, *research entomologist, Forest Insect and Disease Laboratory, Northeastern Forest Experiment Station, Forest Service, USDA, Hamden, Conn. 06514.*

RD&A is the abbreviation for the three basic components of a pest-management program: Research, Development, and Application. Unfortunately, the shortcut is used so loosely we often forget the magnitude and importance of the relationship between the three, and that it takes a super management, communication, and cooperation effort to meld them into a problem-solving unit. The theme for this year's Work Conference, "Techniques for Research, Development and Application," was a direct response to the need for more communication. The objective was to provide a forum where current and proposed techniques could be reviewed, evaluated, and discussed and where cooperation could be fostered.

The workshop topics were chosen from responses to a questionnaire sent to 150 participants in previous Northeastern Forest Insect Work Conferences. The survey indicated an overwhelming interest in all aspects of parasite use in a pest-management program. For this reason, two parasite workshops were scheduled: (1) "Parasite Evaluation," and (2) "Parasite Management." "Evaluation," as it is presently used in conjunction with parasites, has several ingredients; some are qualitative, such as the determination of certain physiological responses to varying environments (diapause, etc.), while others are quantitative, such as the development of sampling schemes for measuring percentage of parasitism. Parasite management emphasizes the effective utilization of parasites in a pest-management program, by inoculative releases, by inundative releases, by enhancement of established parasite populations, or by combinations of the above.

One would suppose that evaluation must precede management if, indeed, management is to exist. But this is more the exception than the rule. The parasite workshops were designed to increase our understanding of the relationship between evaluation and management and to bridge the communication gap that seems to exist between research (evaluation) and application (management).

Techniques for sampling one or more of an insect's life stages was on everyone's list. Importance of sampling in all aspects of research, development, and application was reflected in the excellent participation at the sampling workshop; one got the impression that without sampling a pest-management program was just so much wishful thinking.

Behavioral chemicals have received their share of program time in most insect workshops and symposia in the last 5 years and this Conference was no exception. Very simply, there is a lot of important and interesting work being done, and apparently, people want to know about it. The use of behavioral mediating chemicals (BMC) is relatively new to pest management programs; yet, like many new things, we've tagged them with a super-solution label and dragged them into the development-and-application phase of pest-management programs without completing the research. As with previous so-called "super solutions," BMC has been returned to the laboratory for more intensive investigation. The potential is still there — that's what generates the interest.

The topic "Identification of Insect Pathogens" placed high in the techniques-we-want-to-know-more-about category. Although insect pathogens are primary organisms that affect the dynamics of most insect populations, the expertise required to identify them often precluded their identification so that insect mortality has simply been listed as "diseased." Now, however, several factors, relatively new to forest insect programs, necessitate more precise evaluation of diseased specimens. These are: (1) the use of pathogens as bacteriocides; (2) the necessity of controlling disease in laboratory insect colonies, particularly in mass-rearing programs; and (3) an increased emphasis to identify the factors that regulate insect populations (pest and parasite).

The Northeastern Forest Insect Work Conference was initiated in 1968 as an outgrowth of the Northeastern Forest Pest Council. It is an unstructured organization, with no officers or treasury. Responsibility for organizing each conference rotates between federal, university, and Canadian sponsors; the responsibility is strictly voluntary. Attendance is usually between 50 and 60; in 1975, we had approximately 80.

Why the large attendance? I think it may be related, in an abstract way, to two of the main workshop topics: kairomones and the gypsy moth RD&A program. The word kairomone is derived from the Greek word "kairos," which denotes the senses of opportunistic and exploitative. A kairomone is a behavioral chemical utilized in a beneficial way by the receiver, usually at the expense of the emitter. Kairomones mediate the positive responses of predators to their prey, herbivores to their food plants, and parasites to their hosts. I suggest that the gypsy moth program fits the role of the emitter; emitting ways and especially means ($) for solving a variety of economic and social problems directly related to the scourge of the northeastern woodlands, the gypsy moth.

The program stimulated a positive response, in an opportunistic sense, to discuss the ways and means of solving problems. The workshop participants received the message and responded accordingly. In some cases, it seems, the message and response was instantaneous, leaving little time for advance communication with the host. Considering the checks and balances built into the program, we can expect the emitter, in this case, to gain as much as is expended; the adaptive advantage is obvious.

Our speakers and workshop leaders responded to the problems and kept the communication open and running smoothly. In particular, our thanks go to Charlie Parencia for the last minute pinch-hitting as the lead-off speaker. His paper on the "RD&A in the Boll Weevil Pest Management Program" stimulated our thinking about the present concepts of forest insect RD&A programs and what might be expected once the ways and means for accomplishing the application phase are decided upon.

We had two other excellent invitational papers: "Kairomones and their Role in Pest Management" by W. J. Lewis, Southern Grains Insect Research Laboratory, Tifton, Georgia; and "Gypsy Moth Research, Development and Applications Program: Structure, Objectives, and Direction" by Thomas McIntyre, Gypsy Moth Program Manager, Hyattsville, Maryland.

The workshops were organized and chaired by Drs. Marjorie Hoy (Parasite Evaluation and Management), John Podgwaite (Pathogens, Field and Laboratory), Robert Wilson (Sampling), Gerry Lanier (Behavior Mediating Chemicals), and David Leonard (Open Session). Kathy Shields did a super job organizing a "Demonstration of Equipment and Techniques" session and in addition worked on the Conference Committee with Bert Godwin, Kathy McManus, and myself. Our thanks to all the others who made the Conference go—particularly the participants!

Success of a workshop must ultimately be evaluated by each participant. As organizers we choose to use verbal participation as an index of success — and there was plenty of that!

THE PILOT BOLL WEEVIL ERADICATION EXPERIMENT

by C. R. PARENCIA, JR., *National Program Staff, Plant and Entomological Sciences, Agricultural Research Service, U.S. Department of Agriculture, Beltsville, Md. 20705.*

ABSTRACT. The Pilot Boll Weevil Eradication Experiment was conducted cooperatively with 16 federal, state, and cotton-industry agencies from July 1971 to August 1973. Population-suppression components were late-season insecticide treatments, cultural practices, pheromone traps, insecticide treatment when plants began to square, in-season insecticide treatments, and release of sexually-sterile male boll weevils. After studying the data on completion of the Experiment, the Technical Guidance Committee concluded "that it is technically and operationally feasible to eliminate the boll weevil as an economic pest in the United States by use of ecologically acceptable techniques".

THE BOLL WEEVIL, *Anthonomus grandis*, Boheman, was described in 1843 by Boheman from specimens received from Vera Cruz, Mexico. The first report of the occurrence of the boll weevil in the United States was received by the Department of Agriculture in the fall of 1894 from Brownsville, Texas. C. H. T. Townsend of the Division of Entomology, sent to Texas, found that several counties were infested and that serious damage had been caused by the pest since 1892. It is not the purpose of this discussion to give the history of the spread of the boll weevil in this country, but comments relating to early research seem to be in order.

Townsend's report about the area infested and the life history and habits of the boll weevil was published in March 1895 in INSECT LIFE. He recommended in his report that cotton stalks be destroyed to kill overwintering weevils and that a non-cotton zone be established to prevent further spread of the pest. The Department of Agriculture reported the seriousness of the pest to the Governor of Texas and urged immediate legislation to permit quarantines and remedial work.

By 1895 the boll weevil had spread as far north as San Antonio and as far east as Wharton, Texas; and 1898 was an especially bad year for boll weevils. The Legislature of Texas therefore made an appropriation for research and appointed a state entomologist to investigate means of control. The work on the boll weevil by the Division of Entomology of the Department of Agriculture was therefore discontinued at the end of that season.

Nevertheless, the boll weevil continued to spread; and it was not long—1901—before other states were threatened with invasion. Congress therefore made a special appropriation to support research designed to discover a means of preventing further spread. The resulting program was directed by W. D. Hunter. In 1908, Hunter demonstrated the cultural methods of controlling the boll weevil that had been developed by and were recommended by the Division of Entomology on eight cooperating farms. These farm demonstrations developed into the Farmers' Cooperative Demonstrations of the Bureau of Plant Industry and later into the present Extension Service of the Department.

A laboratory was established at Victoria, Texas, in 1902. This work was moved to Dallas, Texas, in 1905 and from Dallas to Tallulah, Louisiana, in 1909. There it remained until 30 June 1973.

The development of materials capable of controlling the boll weevil is of considerable interest, but time does not permit more than a brief discussion here. Paris green was tested in 1896, but it was not an effective material. In 1908, lead arsenate was formulated as a dust and at first seemed a promising supplement to cultural methods of controlling the boll weevil. However, results were erratic, and the method was not recommended by the Bureau nor used extensively by growers.

Breakthrough

The first breakthrough came when the then new insecticide, calcium arsenate, was used in field tests against the boll weevil in 1916. Although problems with formulation were encountered, sufficient progress had been made by 1921 so that the material was tested in several sections of the Cotton Belt by Tallulah Laboratory personnel. Machines for applying the material were developed at the same time.

The next step in boll weevil control was the application of calcium arsenate dust from airplanes. The use of airplanes was suggested by the success the Ohio Agricultural Experiment Station achieved with aerial applications of lead arsenate for control of catalpa sphinx, *Ceratomia catalpae* (Boisduval), in 1921. However, the first such efforts against cotton insects were made against the cotton leafworm, *Alabama argillacea* (Hübner), in 1922. Thereafter, this method of application rapidly became widespread, and commercial companies soon maintained fleets of airplanes for use in controlling the boll weevil and the cotton leafworm.

Calcium arsenate dust and its application via aircraft was a major breakthrough in boll weevil control, but the insecticide was never widely accepted because its use often caused the development of infestations of the cotton aphid, *Aphis gossypii* (Glover). This pest, if uncontrolled, would cause damage sufficient to offset any benefits obtained by controlling the boll weevil. Nicotine sulfate was developed as an aphicide, but it was difficult and unpleasant to formulate and apply; and it never gained wide acceptance.

The next major breakthrough was the development of organochlorine insecticides. However, the first of them, DDT, did not control the boll weevil. Only when BHC, toxaphene, aldrin, dieldrin, and heptachlor were developed did the growers have more efficient insecticides than calcium arsenate. When these effective materials were mixed with DDT, the mixture controlled both the bollworm, *Heliothis zea* (Boddie), and the boll weevil; and parathion could be used as an aphicide when needed. Thus, once low-pressure low-volume sprays had been developed, growers and researchers felt that the situation was well in hand.

Era of Apprehension

Unfortunately, the era of control with organochlorine insecticides was short-lived. By the mid-1950s the boll weevil had developed resistance. However, in the meantime, methyl parathion, and later azinphosmethyl, were developed for control of the boll weevil.

The threat of resistance therefore created an era of apprehension. Spokesmen for the cotton producers repeatedly emphasized that the survival of the industry depended on adequate research designed to strengthen the ability of U.S. producers to compete for markets. Leading scientists and spokesmen for industry agreed that the presence of the boll weevil in cotton-producing areas posed a major and costly problem for the cotton industry and that research support was an urgent need. As a result, in the Agricultural Appropriation Report for fiscal-year 1959, both the House and Senate Agriculture Committees requested the Secretary of Agriculture to review the boll weevil problem and submit a report on research and facility needs.

The Office of the Secretary appointed a working group consisting of E. R. McGovran of the Cooperative State Research Service USDA; H. G. Johnston of the National Cotton Council of America; and E. F. Knipling (chairman) and C. R. Parencia (secretary) both of Agricultural Research Service, USDA to study the problem and to (1) develop information on current research programs devoted to boll weevil investigations by state federal, and private industry; (2) determine the needs for an overall comprehensive research program; and (3) determine the broad areas of research that would be appropriate for federal attention and support in an effor to help meet the overall needs.

The Working Group on Boll Weevil Research Programs made its study and submitted its report dated 30 December 1958. The study culminated in the appropriation o funds by Congress for the establishment of the Boll Weevil Research Laboratory at State College (now Mississippi State), Mississippi, and the strengthening of ongoing research programs at the Cotton Insect Research Laboratories at College Station, Texas; Baton Rouge, Louisiana; and Florence, South Carolina. The new research facility at Mississippi State was dedicated in a formal ceremony in March 1962. Research on the boll weevil was simultaneously strengthened in several of the state agricultural experiment stations.

Significant research findings resulting from the expedited research on the boll weevil were: (1) Techniques for mass-rearing the boll weevil; (2) development of the reproduction-diapause control program; (3) development of ultra-low-volume spray applications of insecticides; (4) development of the systemic insecticide, aldicarb, that controls the boll weevil; (5) finding that the male boll weevil emits a pheromone that attracts females and also acts as an aggregant; (6) identification and synthesis of the attractant, grandlure, and development of traps baited with it for capturing boll weevils; (7) progress in development of a chemosterilant making the male-sterile release technique feasible; (8) use of trap crops treated with aldicarb in furrow and as a sidedressing together with grandlure bait in reducing overwintered boll weevil populations; and (9) progress in the development of a frego bract cotton with considerable resistance to the boll weevil.

In recognition of the importance and urgency of eliminating the boll weevil problem as soon as it became technically and operationally feasible, the National Cotton Council of America in its 1969 annual meeting established a Special Study Committee on Boll Weevil Eradication. The Special Study Committee met in Memphis, Tennessee, on 6 May 1969 to review the status of current knowledge on boll weevil suppression measures and to consider actions that should be taken in efforts toward the elimination of the boll weevil as a pest of cotton. The chairman of the Special Study Committee appointed a subcommittee to select areas representative of boll weevil conditions in the southeastern, southern, and southwestern areas of the Cotton Belt that would be suitable for undertaking large-scale experiments to determine if boll weevil eradication was feasible with currently available suppression techniques. The subcommittee made its study and prepared a report dated 15 August 1969, which was presented to the Special Study Committee on Boll Weevil Eradication in Memphis, Tennessee, on 16 September 1969. It recommended that a pilot boll weevil eradication experiment be conducted beginning in calendar year 1970 in an area centered in Southern Mississippi and including adjacent cotton areas in Alabama and Louisiana.

Experiment Financed

The Special Study Committee accepted the recommendations of the subcommittee, and its representatives met with Department of Agriculture officials to discuss ways of financing the experiment. A decision was made that the project would be financed by $1 million from ARS (later with APHIS), $500,000 from CSRS, and $500,000 from industry, Cotton Incorporated, for each of 2 years. Mississippi was to provide a rearing facility. After a detailed study of the area was made, the estimated cost of the experiment was $2.5 million. Since only $2 million was available, the experiment was delayed for a year or until the needed additional funds could be obtained. However, in 1971 the new cotton program resulted in a considerable reduction in the cotton acreage to be planted, making it possible to start the experiment with available funds. The director of science and education appointed a technical guidance committee for the pilot boll weevil eradication experiment.

The experiment got under way in July 1971. It was conducted cooperatively with the departments of agriculture, experiment stations, and extension services of Mississippi, Louisiana, Alabama, and Texas; with Cotton Incorporated and the National Cotton Council representing the industry; and with USDA's APHIS, ARS, CSRS, ASCS, and ES.

The reproduction-diapause phase of the experiment was carried out in the fall of 1971. Unfortunately boll weevil populations were very heavy; and as a result of the mild winter, survival of boll weevils was high. A trap crop treated with aldicarb was planted in each field in the eradication and first buffer areas, and pheromone traps at the rate of two per acre were placed around each field in 1972. An insecticide application was made when plants began to square. A period of dry weather resulted in late emergence of weevils from hibernation sites, leaving too many weevils in the fields for the sterile-male releases to be effective. Five in-season applications of azinphosmethyl were made, followed with 13 applications for reproduction-diapause control. By October adults were too scarce to be detected. Pheromone trap catches in the spring of 1973 indicated very low surviving populations in the eradication and first buffer areas. Release of sterile males began in early June, but rearing problems made it necessary to reduce releases to 50 per acre instead of the hoped for 100 in the eradication area and extending only 5 miles into the first buffer area. It was originally planned that both areas receive 100 sterile males per acre per week. Fields with infestations in the remaining first buffer fields were to be treated with insecticides. Only 33 of the 236 fields were found to be infested in the eradication area, and they were in the northern zones nearest the first buffer. Strong evidence indicated that the problem was caused by migration from the second buffer, where overwintering populations were considerably higher. The infested fields were treated at 3-day intervals with azinphosmethyl. As a result of these treatments, reproduction could not be detected in 32 of the 33 fields at the end of the experiment. The infestation in the one field was not detected until the last week of the experiment, so insufficient time did not permit the total elimination of reproduction in it.

The experiment was terminated on 10 August 1973. The Technical Guidance Committee met on 30 August to evaluate results obtaine in the experiment. After studying the data it concluded ". . . that it is technically an operationally feasible to eliminate the bol weevil as an economic pest in the Unite States by the use of techniques that ar ecologically acceptable".

The National Cotton Council's Specia Study Committee for Boll Weevil Eradicatio met in Memphis, Tennessee, on 10 Januar 1972 to review the progress and status of th experiment. The Committee expressed a nee for a comprehensive eradication plan tha would outline areas for initiation and subsequent target zones, timetables, probabl costs, program requirements, operational arrangements, and the like. The chairman appointed a technical committee to develop plan for overall boll weevil eradication.

Though two preliminary meetings wer held in November 1972 and early Januar 1973, the work of the Committee did not gai impetus until results of the experiment became available at the end of August. A overall Plan for a National Program to Eliminate the Boll Weevil from the United State was presented by the technical committee t the Special Study Committee on 4 Decembe 1973. It was accepted and in turn was presented to the Secretary of Agriculture on 1 December. In the Agricultural Act of 197 the Secretary had been instructed to carr out elimination programs for the boll weevi pink bollworm and other cotton insects if h determined that it was feasible to do so. Th elimination plan became quite controversi in the scientific community for various reasons. Finally, an agreement was reached t conduct an eradication trial on some 100,0 acres in northeastern North Carolina ar Virginia. The Department supports the tria but it was not funded for fiscal-year 1976.

KAIROMONES AND THEIR ROLE IN PEST MANAGEMENT

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ABSTRACT. Chemical cues emanating from the host insects and acting by themselves or together with host-plant components appear to be the key factors governing host-location by parasites. A summary-analysis of the studies of these kairomones, their involvement in the behavior sequence of host selection by parasites, and the basis for their potential employment in pest management are presented.

MANY INVESTIGATIONS, beginning with an observation by Thorpe and Jones *(1937)*, have demonstrated that the behavior of parasitic insects is influenced in various ways by chemicals produced by their hosts. One of the most interesting aspects of the behavior of parasites and the major determinant of their efficiency as a control agent are the behavioral patterns involved in host selection.

Salt *(1935)*, Flanders *(1953)*, and Doutt *(1959)* separated host selection by parasites into essentially four consecutive processes. These steps are: host-habitat finding, host finding, host acceptance, and host suitability. Our discussion will deal primarily with the first two steps of this process, which we will consider collectively as host location.

In the studies of entomophagous insects at our laboratory during the last few years, we have placed a great deal of emphasis on kairomones. [Kairomones are chemical messengers released by an individual of one species that induce a behavioral or physiological response in an individual of another species that derives adaptive benefit *(Brown et al. 1970)*].

The purpose of this presentation is to summarize these studies and then to analyze their overall meaning.

Demonstration and Description of Response to Kairomones

The initial studies involved the braconid, *Microplitis croceipes* (Cresson), an important parasite of the larval stage of the corn earworm, *Heliothis zea* (Boddie) *(Lewis and Jones 1971)*. The ovipositing female parasites use fecal and other frass material voided by the hosts as a mediator for finding the host larvae. Contact with the frass results in an intensive host-seeking response involving a thorough examination of the surrounding substratum with their antennae in search of a host.

The minute trichogrammatid parasites of lepidopteran eggs, *Trichogramma* spp., were found to orient to chemicals left by moths during oviposition. Salt *(1935)* and Laing *(1937)* reported that size, shape, and color of eggs were criteria used by ovipositing females of *Trichogramma evanescens* Westwood for selecting hosts. Salt *(1935)* demonstrated that host eggs have no characteristic of themselves that allows the parasite to find them from a distance and that sight of the eggs (2-3 mm) was the method of perception. However, Laing *(1937)* demonstrated that parasites did perceive an odor left by the adult moth. Our studies have demonstrated that the *Trichogramma* do respond to kairomones from the moths and that these kairomones are very important parts of host location by females of *T. evanescens (Lewis et al 1971)*.

Differential Response to Various Host Species

Parasites usually exhibit an attack preference for one host species over another when more than one potential host species is available. The response of *M. croceipes* females to larval feces of various lepidopteran species was evaluated *(Lewis and Jones 1971)*. Intense responses comparable to those from *H. zea* were elicited by feces of *Heliothis virescens* (F.). *Heliothis virescens* is a frequent host for this parasite. Definite but considerably weaker responses were elicited by feces from larvae of the fall armyworm, *Spodoptera frugiperda* (J. E. Smith); the beet armyworm, *S. exigua* (Hübner); and the cabbage looper, *Trichoplusia ni* (Hübner); all three of which *M. croceipes* will sting, but on which development does not occur. No response was obtained to feces of the almond moth, *Cadra cautella* (Walker) or the Indian meal moth, *Plodia interpunctella* (Hübner), neither of which is stung by females of *M. croceipes*.

Ashley et al. *(1974)* demonstrated in field-cage studies that *Trichogramma pretiosum* Riley had a constant preference for *H. zea* eggs over *T. ni* eggs, in that higher numbers of *H. zea* eggs were parasitized, even when *T. ni* eggs were more abundant. We conducted studies to determine the role of kairomones in determining this higher attack of *H. zea*, and found that this strain of parasites was more efficient at finding eggs associated with kairomones of *H. zea* moths than moths of *T. ni*.

Chemistry of Kairomones

A few of the chemical mediators involved in host selection by parasitoids have been identified and are summarized in table 1. The chemicals in the frass of *H. zea* responsible for the host-seeking response previously described for *Microplitis croceipes* were identified by Jones et al. *(1971)*. The active components, extracted from the frass of the host larvae were a mixture of 7, 9, 11, 13, and 15 methylhentriacontanes. The mass spectrum indicated the 13-methyl isomers as the most abundant. Synthesis and bioassays of the possible isomers showed that the 13-methylhentriacontane was the most active component. Females of *M. croceipes* respond to as little as 50 ng of this compound, but 150 ng is required for consistent and strong responses.

Similar chemicals have been identified as the host-seeking stimulants for *Cardiochiles nigriceps* Viereck *(Vinson et al. 1975)*. The active chemicals are the mono-methyl hentriacontanes, dotriacontanes, and tritriacontanes. The most active methyl position was 11 for hentriacontane, 16 for dotriacontane, and 13 for triacontane. Optimum activity was obtained with a 50-ng mixture of these three compounds.

Hendry et al. *(1973)* identified the host-

Table 1.—*Chemicals identified as kairomones of parasitic insects*

Parasite	Host	Type of stimulus (refer to fig. 1)	Chemical	Source	Reference
Microplitis croceipes	*Heliothis zea*	S_3	13-methylhentriacontane	Hemolymph, cuticle, frass	Jones et al. (1971)
Cardiochiles nigriceps	*Heliothis virescens*	S_3 and S_4	11-methylhentriacontane 16-methyldotriacontane 13-methyltriacontane	Mandibular gland	Vinson et al. (1975)
Orgilus lepidus	*Phthorimaea operculella*	S_3 or S_4	Heptanoic acid	Mandibular gland	Hendry et al. (1973)
Trichogramma evanescens	*Heliothis zea*	S_3	Tricosane	Hemolymph adult cuticle	Jones et al. (1973)
Archytas marmoratus	*Heliothis zea*	S_6	Protein	Feces, hemolymph	Nettles (1973)
Venturia canescens (Gravenharst)	*Anagasta kuehniella* (Zeller)	S_6	Unknown	Mandibular gland	Corbet (1971)
Itoplectis conquisitor (Say)	*Galleria mellonella* (L.)	S_6	Amino acids	Hemolymph	Arthur et al. (1972) Hedekar & Art (1973)
Cheiloneurus noxius Compire	*Coccus hesperidum* L.	S_5	Protein	Hemolymph	Weseloh & Bar (1971)

seeking stimulant of *Orgilus lepidus* Musebeck, a parasite of the potato tuberworm, *Phthorimaea operculella* (Zell), as heptanoic acid. The parasite also responds to hexanoic acid and to a much lesser extent to valeric and octanoic acids.

The kairomones for inducing search behavior in *Trichogramma evanescens* were determined by Jones et al. *(1973)*. These parasites respond to docosane, tricosane, tetracosane, and pentacosane, constituents of the scales of its host moth. Tricosane, the most active component, increases parasitism in petri dishes when used at a rate of 6 pg/cm^2. Tricosane effectively increased parasitism on live plants in the greenhouse at 250 pg/cm^2.

The fact that these chemicals serve as kairomones is not their *raison d'etre*. However, the primary functions of all of them have not been elucidated. The saturated hydrocarbons are part of the waxy layer of the cuticle and serve as a water barrier, protecting the insect from dessication. Their presence in the mandibular gland is not as clear, but they probably lubricate the ingested food. They are also present in the hemolymph, probably serving as precursors to new cuticle formation *(Gilbert 1967)*. Synthesis probably occurs in the oenocytes *(Wigglesworth 1972)*. Their presence in frass is, in part at least, mandibular gland excretion and exuvia consumption.

The amino acids are, of course, common intermediary metabolites, and the proteins could serve any of a large number of functions. The nature of the heptanoic acid is unknown.

Manipulation of Field Behavior

Kairomones can be used to manipulate the field behavior of *Trichogramma (Lewis et al. 1972)*. A comparison was made of the incidence of parasitism on alternating kairomone-treated and control leaves in a cotton field. Leaves were selected and marked at 1-foot intervals. Every other marked leaf was sprayed with a hexane extract of *H. zea* moth scales while the alternating control leaves were sprayed with plain hexane. *T. evanescens* adults were released throughout the plot. On each day for 5 subsequent days, one

Table 2.—*Parasitism of C. cautella by T. evanescens on cotton leaves sprayed with hexane extract of moth scales and on cotton leaves for 5 days subsequent to treatment and release of parasites*

	Host eggs					
		Dissected		Held for development		
Day and treatment[a]	No.	No. dissected	No. with 1 or more parasites[b]	No. held	No. that produced parasite adults[b]	No. parasite adults produced
1 T	132	40	10	92	32	—
C	143	40	4	103	8	—
2 T	167	39	11	128	28	30
C	157	40	8	117	16	20
3 T	170	44	21	126	42	50
C	149	46	7	103	40	25
4 T	140	40	12	100	12	13
C	146	40	7	106	5	6
5 T	102	39	4	63	2	3
C	102	39	0	63	1	1
Total						
T	711	202	58 a	509	116 a	96 a
C	697	205	26 b	492	50 b	52 b

[a] T=treated, C=control.

[b] Treated and control totals, by column, not followed by the same letter are significantly different at the 5-percent level as determined by paired t-test.

host egg was placed on each of the marked leaves and re-collected after 3 hours exposure. Some of the eggs were dissected and the remainder were held to allow development of the parasites. The result was that approximately twice as many of the eggs on the treated leaves were parasitized and produced about twice as many adults for each of the 5 days subsequent to treatment and release (table 2).

Another field study was conducted to determine the effect of synthetic kairomone and to determine whether it could be used to increase parasitization by natural *Trichogramma (Lewis et al. 1975a)*. The appraisal was made on crimson clover. Ten pairs of plots 10 x 10 feet were selected, and one plot of each pair was sprayed with tricosane at a rate of 1200 mg/acre. Then 75 eggs of *H. zea* were placed in each plot and re-collected after 24 hours exposure. The parasitization, all due to naturally-occurring *Trichogramma* spp., was significantly higher in the treated plots (13 percent) than in the control plots (4 percent). Positive results have been obtained with as little as 150 mg/acre. Similar results were obtained against naturally deposited eggs.

Mechanisms Causing Increased Parasitization

Studies were made to elucidate the behavioral modifications causing the increased parasitization by *Trichogramma (Lewis et al. 1975b)*. The kairomone serves as a sign stimulus to activate a host-seeking behavior resulting in more efficient location of eggs in areas with the kairomone. The kairomone did not have the effect of an attractant, nor did it arrest them only to the substrates possessing the kairomone. Therefore, the limitations of confusion and disorientation did not occur.

Also in the plots having the appropriate kairomones with the proper distribution, better retention of the parasites in the target area resulted from the host-seeking behavior being continually reinforced.

In addition, there was a better distribution of the parasite eggs among the host eggs (less duplication) in plots treated with kairomones as compared to control plots. The presence of the kairomone on the surrounding plant surfaces probably induces the ovipositing females to depart more rapidly from host eggs that they have stung and to go in search of other hosts. The absence of the kairomone from the surrounding substratum would result in the wasps lingering on and repeatedly stinging each host that it found.

Interpretation of Host-Location Sequence

A diagram of what we consider to be the basic pathways of host location and selection is presented in figure 1. The solid lines show the processes that occur if the necessary stimuli are provided at each step. The dotted lines show the alternative processes that occur if the necessary stimuli for the subsequent step are not present. This diagram is a generalization and includes the basic components. Additional substeps and minor alternative pathways are involved and can be incorporated with the discussion of an individual species. For a detailed discussion of this sequence, refer to Lewis et al. *(1975b)*. For our purpose, presently we can say that the host-selection process consists of a sequence of behavior acts (fixed action patterns) each of which must be released by the appropriate releasing stimuli. An analysis of this sequence can be of great importance in identifying key points for parasite manipulation in pest-management programs.

The T_3 and T_{-3} transitions and the associated stimuli (S_3: frass, moth scales, decomposition products, or some other cues associated with the presence of hosts in the environment) between scanning of the habitat and the more thorough investigation of host trails within the habitat are the processes of primary interest in our studies of kairomones and their use in pest management. In order for females of insect parasites to remain and effectively search a desired target area, necessary stimuli (S_3) to produce the T_3 transition must be provided. Contact with the mediator that releases this behavior pattern must occur periodically to reinforce

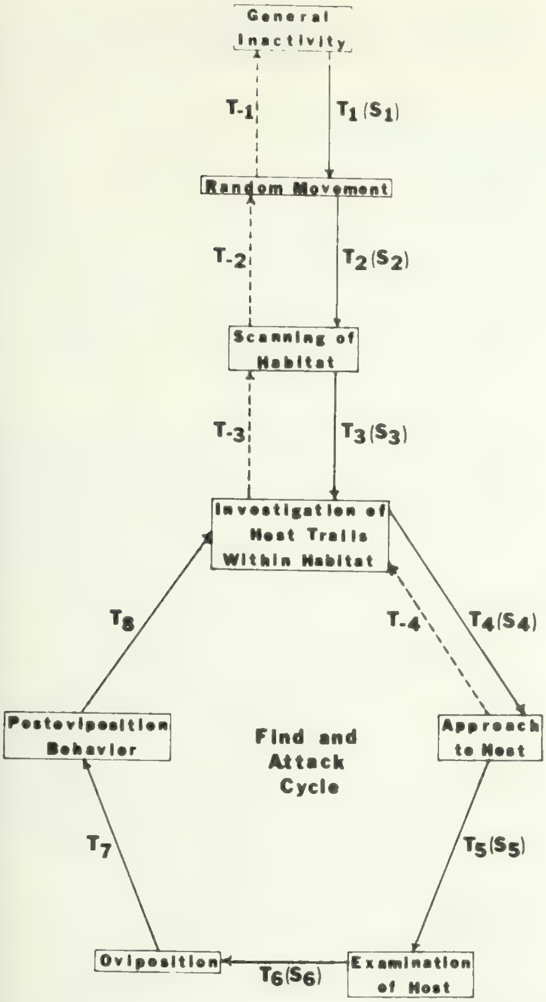

Figure 1.—Basic sequence of host-finding activities by females of parasitic insects:

T_1 to $_8$ and T_{-1} to $_{-4}$ = transitions among the indicated behavioral acts.
$S_{1\text{-}6}$ = stimuli releasing the indicated behavioral patterns.
S_2 = olfactory, visual, and physical cues associated with host plants or other habitats.
S_3 = primarily chemical cues from frass, moth scales, and decomposition products associated with the presence of host insects.
S_4 = olfactory, visual, auditorial, and other chemical or visual cues from host insect.
S_5 and $_6$ = olfactory, tactile, auditorial, and/or combination of these cues from host individual.

and maintain the process. Lack of sufficient reinforcement otherwise allows the T_{-3} reversion to general scanning and a loss of the parasite from the target area. Such an adaptation is obviously of importance to the parasite in nature to prevent them from searching in areas where there is a lack of or too low densities of the appropriate host.

The ability to manipulate the behavior of parasites at this point of the host-finding sequence is obviously of great potential importance for more effective utilization of parasites in pest-control programs.

Prerelease Stimulation Principles

Successful establishment and retention of entomophagous insects in target areas is of foremost concern in making augmentative releases. This involves overcoming the insect's innate tendency to escape and disperse upon release, as well as releasing a host-seeking behavior that will predominate until the parasite becomes established within the habitat. Kairomones as host-seeking stimulants can play a vital role in accomplishing this desired effect.

Kairomones were evaluated by Gross et al. *(1975)* as sign stimuli at time of release to determine whether the egg parasites, *T. achaeae* Nagaraja and Nagarkatti and *T. pretiosum,* and the larval parasite *M. croceipes* could be stablized and oriented in a host-seeking pattern, thus increasing their frequency of retention in the target area and thereby improving their overall efficiency.

The results obtained with *T. achaeae* can be taken as an example. *T. achaeae* were placed in jars, the inner surfaces of which had been treated with tricosane at the rate of 1μg/30 cm². The parasites were held in these jars for 5 minutes just before release. Controls were held in untreated jars in a similar manner. Equal numbers of treated and control *T. achaeae* were released in separate plots of whorl-stage corn, and the parasitism was monitored for the subsequent 24 hours. The prior exposure to the kairomone resulted in increases in parasitism from 10 to 80 percent (table 3). Thus activation of the parasites before release results in an improved performance in the target area.

Table 3.—*Comparative parasitism of eggs of* H. zea *by tricosane stimulated and non-stimulated* T. achaeae *released in field plots of whorl stage sweet corn*

Item	Percentage of eggs parasitized at day —							
	1	2	3	4	5	6	7	8[a]
Stimulated	53.8	37.6	60.3	10.0	4.3	3.6	22.1	44.6
Non-stimulated	48.5	21.4	42.3	7.4	2.4	4.7	14.8	51.0
Difference	8.0	T=2.446**		—	—	—	—	—

[a] Day 8 not included in the statistical analysis.

** Significant at the 0.01 level of probability.

Similar results were obtained with *T. pretiosum* and *M. croceipes.*

Effect on Longevity and Total Productivity

Studies presented demonstrate that treatment of an environment with the kairomone increases the rates of parasitism in that area for several days after application. However, it is important to consider the effect of continuous exposure to the kairomone on the total productivity and/or longevity of the ovipositing parasite, and as to the possibilities of causing habituation or related effects by getting the supply of kairomone out of balance with the host supply.

Studies were conducted by Nordlund et al. *(1975)* to examine the effects of kairomones on productivity and longevity. Pairs of freshly emerged *T. pretiosum* (1 male and 1 female) were containerized in 25 x 200-mm test tubes (1 pair/tube), and each tube was designated as treated or control. Eggs of *H. zea* were glued on 20 x 160-mm strips of paper (20 eggs/strip), and one strip was placed in each tube. The strips for the treated tubes were sprayed with the standard moth scale extract; the control strips received no spray. At 24-hour intervals, the strips were exchanged and the condition of the parasitoids was determined. The strips removed daily were monitored to determine the percentage of parasitization and the progeny produced.

Constant exposure to the kairomone actually increased longevity. The mean longevity for females was 10.6 (±1.63) for the control and 12.2 (±1.6) for the treated females (P=0.01). Ashley et al. *(1974)* found that *T. pretiosum* females lived longer when provided naturally deposited *H. zea* versus *Trichoplusia ni* eggs for hosts and suggested the difference may have been the different stimuli received from the two host species by the ovipositing parasite.

Data demonstrate that the daily level of parasitization was higher in the treated tubes (50.4±2.9) than in the control tubes (43.0±2.5). Also, the total progeny produced was higher in the treated tubes (110.8±10.6): 54.2 males and 56.6 females/tube as compared to the control tubes (80.6±7.7), 37.9 males and 42.7 females/tube.

Nordlund et al. *(1975)* also examined the possibility of habituation in these tubes where they were in constant exposure with the kairomone in the absence of eggs. Habituation did not occur when they were placed under such conditions for 3 days and they continued to exhibit a response to the kairomone.

Summary and Conclusions

The behavior patterns involved in the host or prey selection of entomophagous insects are the major determinants of their efficiency as a controlling agent.

It has become increasingly evident that these behavioral patterns must be better understood and that techniques developed for controlling them in order to increase the dependability of entomophages in pest-management programs. It is not enough to simply release the agent in large numbers. We must have the ability to adequately select the proper species or strain and then manage their dispersal and activity so as to retain them in the target areas and maintain effective activity.

Studies of kairomones have helped develop a better understanding of the overall host-selection sequence of insect parasites. The kairomones acting as stimuli in the host-finding process offer good potential as guides for selecting appropriate species and strains for colonization and for adding greater versatility in their application. Several avenues for the use of kairomones in importation, conservation, and augmentation programs appear worthy of consideration. A brief summary of their potential utilities in local and regional augmentation programs are as follows:

A. Local Programs:
   1. Prestimulation of released beneficial insects to stabilize and orient them at time of release.
   2. Treatment of plant surfaces for stimulation of natural and/or released entomophages.
      a. Supplying appropriate chemical from host or prey insect to elicit and maintain effective search.
      b. Supplying appropriate chemical from host plant for intercepting and activating search.
   3. Integrating kairomones with food sprays and artificially supplied host or prey insect material.

B. Regional Program — Application of appropriate kairomone to selected host plants throughout an area for suppression of total pest population by:
   1. Decrease of early-season pest buildup by improving the activity of the predators and parasites.
   2. Increasing the production of parasites as a result of higher parasitism level.
   3. Stepped-up development of predators as a result of increased feeding.

Further studies of these kairomones should continue to yield an improved understanding of parasite-host relations and provide a greatly improved basis for the use of parasitic insects in pest-management systems.

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GYPSY MOTH RESEARCH, DEVELOPMENT, AND APPLICATIONS PROGRAM: STRUCTURE, OBJECTIVES, AND DIRECTION

by THOMAS McINTYRE, *program manager, U.S. Department of Agriculture Gypsy Moth Research, Development, and Applications Program, Washington, D.C.*

ABSTRACT. Because of the urgent need to control forest insect pests, a research-and-development program was established to accelerate research to provide control technology. The facilities, objectives, funding, and organization of the program are described.

IN 1973 THREE INSECTS — the Southern pine bark beetle, the gypsy moth, and the Douglas-fir tussock moth — were epidemic in the South, Northeast, and Northwest respectively. Outbreaks of these pests can be expected to continue, although intensity and extent of infestation will vary considerably in place and time.

Secretary Butz and Assistant Secretary Long of the U.S. Department of Agriculture became thoroughly familiar with these major forest pest problems. Review showed that effective strategies and techniques for dealing with these insects were lacking or inadequate. Further study showed that resources available within the Department were not adequate to provide the required pest-management techniques within a reasonable time.

Recognizing the urgent need to control these insects and prevent similar outbreaks in the future, Assistant Secretary Long asked four federal agencies — the Animal and Plant Health Inspection Service, the Agricultural Research Service, the Cooperative State Research Service, and the Forest Service — to develop plans for a research-and-development program that would provide the needed control technology. It was requested that these programs be structured so that specific objectives could be met in 4- or 5-year programs. It was determined that the longer research period would be required for the Southern pine bark beetle effort.

Staff specialists in Washington, D.C., and from the field, including scientists from several universities, developed proposed research programs outlining specific objectives and including estimated budgets. I will outline the proposed programs and the funds requested to complete the research. The structuring for these research-and-development efforts for the three insects is identical. Therefore I will not outline details on the three pest problems, but will limit my remarks to the gypsy moth program.

The present funding for the ongoing gypsy moth research-and-development program is $2.3 million. Examination of the resources available indicated that they were not adequate to provide the needed control technology within a short time. Considerable acceleration of the program was indicated.

An analysis of available resources revealed research-and-development capability at the following faciities:

Forest Service laboratories. — Hamden, Connecticut; Delaware, Ohio.

Forest Service pest-control centers. — Hamden, Connecticut; Upper Darby, Pennsylvania.

Agricultural Research Service Laboratories.—Beltsville, Maryland; Newark, Delaware; Serves, France; Tokyo, Japan.

Animal and Plant Health Inspection Service Laboratories.—Otis Air Force Base, Cape Cod, Massachusetts.

Universities in the Northeastern United States.

Accelerated Program of Attack

Here is a summary of the program objectives and expected results in the accelerated gypsy moth research-and-development program:

Objectives:

- Monitor and predict moth populations and damage
- Develop materials and strategies for suppressing moths
- Provide integrated pest-management strategies

Expected Results:

- Methods for detecting, evaluating, and predicting changes in moths and damage
- Methods for using toxicants, microbials, behavioral materials, parasites, predators, pathogens, and sterile males
- Technology for managing or eradicating moths in chronic infestations and isolated areas

To achieve the objectives and provide the anticipated results, a 3-phase strategy/activities/cost program was developed:

	Million dollars
PHASE I — Predicting populations and impacts:	
Predicting populations	2.0
Predicting impacts	1.4
Integrating changes and impacts	0.7
	4.1
PHASE II — Developing techniques for control of moths:	
Parasites and predators	2.0
Microbials	2.3
Disparlure	3.9
Toxicants	1.3
Sterile males	.2
Mass rearing	.8
Chemostimulants	.5
	11.0
PHASE III — Providing integrated pest management systems:	2.3
Total, FY '75-'77	17.4

Assistant Secretary Long and the support staff met in the summer of 1974 with Office of Management and Budget personnel and congressional committees to deal with matters involving funding of the three accelerated insect research-and-development programs. Funds were obtained for each of the three programs, and the table outlines budgets for the Combined Forest Pest Research and Development Programs.

Organizational Structure

Interagency and university involvement in the forest-insect pest programs suggested the need for new organizational structures. Key points are the Program Manager and the Program Board.

The Board is composed of the agency heads from the Forest Service, Animal and Plant Health Inspection Service, Agricultural Research Service, Cooperative State Research Service, and a representative from the Association of State College and University Forestry Research Organizations. The Program Board will be expanded to provide for several more members to obtain adequate inputs from individuals with specialized interests. The Deputy Assistant Secretary for Conservation, Research and Education (currently Mr. Vander Myde) chairs the Board. He is assisted by a staff officer who carries out staff functions. Keith R. Shea, formerly in charge of forest insect and disease research in the Forest Service, was appointed to this position.

The Program Manager is considered the key to eventual success of these accelerated research-and-development efforts. The Program Manager reports directly to the Board. He has operational responsibility for project planning, implementation, review, and control. Personnel, funds, and facilities are supplied by an appropriate administrative management unit of the Forest Service. The Program Manager consults on major decisions with the agencies or institutions providing resources.

The Program Manager is authorized to use all the instruments of management available to USDA Agencies. In addition to in-house mechanisms, these include cooperative agreements, grants, and contracts with universities, state governments, and private

Table.—*USDA forest pest programs, budget summary*

[In millions of dollars]

Fiscal-year	Douglas-fir, tussock moth	Gypsy moth	Southern pine bark beetle	Total
1975	2.0	4.8	2.5	9.3
1976	3.0	7.9	4.4	15.3
1977	2.7	6.0	4.3	13.0
1978	.5	.2	4.1	4.8
1979	—	—	4.3	4.3
Total	8.2	18.9	19.6	46.8

institutions. Funds are allocated in accordance with activity needs regardless of source. Support provided to the universities is at least equal but not limited to funds appropriated to the Cooperative State Research Service for this project.

PARASITE EVALUATION AND MANAGEMENT

by MARJORIE A. HOY, *the Connecticut Agricultural Experiment Station, New Haven; now a research entomologist, Forest Insect and Disease Laboratory, Northeastern Forest Experiment Station, Forest Service, USDA, Hamden, Conn. 06514.*

THE WORKSHOP on Parasite Evaluation was attended by approximately 60 people the first day and by about 40 people the second day, surely an indication of the interest held by many in gypsy moth parasites. The agenda was followed fairly closely by the contributors, and questions and answers from the audience were numerous.

The invited contributors were: Jack Coulson, Chief, Beneficial Insects Introduction Research Laboratory, USDA, ARS, Beltsville, Md. 20705; Larry Ertle, Quarantine Officer, USDA, ARS, Newark, Del. 19713; Timothy Tigner, Division of Forestry, Commonwealth of Virginia, Charlottesville, Va. 22903; Ronald Weseloh, The Connecticut Agricultural Experiment Station, New Haven, Conn. 06504; Mark Ticehurst, Bureau of Forestry, Middletown, Pa. 17057; Thomas ODell, Northeastern Forest Experiment Station, U.S. Forest Service, Hamden, Conn. 06514.

The purposes of the workshop as seen by the chairwoman were twofold: (1) to impart information about work going on in various laboratories and organizations, and (2) to attempt to reach a concensus about the direction the new gypsy moth parasite program should go, particularly with reference to priorities in foreign exploration.

With respect to goal 1, I believe that much information was exchanged between various people working with gypsy moth parasites. Jack Coulson discussed problems and limitations during foreign collection and quarantine handling due to the limitations on funds and personnel. Larry Ertle noted that his capacity to provide detailed information about exotic species during quarantine was severely limited by the huge workload he was inundated with each season.

Jack Coulson placed considerable emphasis upon receiving information from research people involved with gypsy moth parasites. Specifically, he would be glad to have a foreign data sheet with desired information to give to foreign field personnel. Furthermore, he would like to have information from people interested in working with gypsy moth parasites and a return from them of the information they are able to obtain. It appeared that there are increasing numbers of research people interested in various types of evaluation of new exotic gypsy moth parasites.

Considerable discussion concerned multiple vs. single introductions. A consensus seems to be that single introductions are the extreme at one end, while the extreme multiple system is not as productive as something in between; i.e. the chairwoman, at least, felt that people attending might vote for increased study of the new exotics prior to importation, and a moderately selective introduction scheme.

The Parasite Management Workshop on Thursday morning was made available to the group to continue the discussion. Thus, part II of the agenda was covered then. Mark Ticehurst was able to give a clear, concise summary of the work the Pennsylvania group is doing. Tim Tigner discussed the values of percentage of parasitism in parasite evaluation. Open discussion made it clear that percentage parasitism, while not the ideal method of evaluation, does have its uses, particularly when gypsy moth population densities, etc., are given. Certainly percentage of parasitism is sufficient to determine establishment, although its value in relation to efficacy are open to considerable debate. It may be of value also in evaluation of management techniques.

Alternative methods of evaluation were discussed by Ron Weseloh. He mentioned various sampling and behavioral analyses he has used in an attempt to evaluate several gypsy moth parasites. He also reviewed a paper by Price about predicting effectiveness through measurements of niche breadth *(Price 1972)*.

Nothing along these lines appears to have been done with gypsy moth parasites, and perhaps analyses such as these could provide valuable information. In addition, Ron tried to open the discussion up to other classical biological-control techniques and their relationship to evaluation of gypsy moth parasites. These included experimental removal of parasites; insecticidal check methods, and mechanical exclusion such as caging or hand-removal, and interference techniques. Their adaptation to gypsy moth parasites is open to question.

Finally, Tom O'Dell discussed various aspects of his and Bert Godwin's evaluations of *Blepharipa pratensis*. These include studies of behavior in the field and laboratory, including sampling methods, with the ultimate goal of sampling all stages of *Blepharipa* to develop a life table.

Assuming that the lines of communication developed and widened during the workshop are maintained during the coming year, I believe the workshop was positive— time well spent.

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FIELD AND LABORATORY IDENTIFICATION OF INSECT PATHOGENS

by JOHN D. PODGWAITE, *research microbiologist, Forest Insect and Disease Laboratory, Northeastern Forest Experiment Station, Forest Service, USDA, Hamden, Conn. 06514.*

An understanding of disease processes occurring in insects is basic to any RD&A program involved with pest management. It is of course essential to a program like the gypsy moth program that stresses the utilization of microbial agents for pest control.

The first step in the development of a microbial control agent is to find it. The next step is to identify it and determine how it kills the insect. The successful accomplishment of these steps and the other logical developmental steps (safety testing, production, field testing) depends on the utilization of a variety of diagnostic procedures and techniques.

There are of course other areas of an RD&A program where a knowledge of disease and pathogens is important; for example, in population dynamics studies, where the identification of disease conditions are necessary for building life tables. Also, the successful establishment and maintenance of insect cultures necessitates a need for diagnosing, treating, and then avoiding disease problems.

The workshop discussions focused on some of the techniques utilized to diagnose disease conditions both in the field and in the laboratory and on how these techniques are used in RD&A program studies.

Normand R. Dubois, microbiologist, USDA Forest Service, presented the general techniques of insect pathology and microbiology used to diagnose disease conditions in insects. He indicated that there are many techniques the untrained field worker can use to diagnose disease in field populations. Some rapid staining and microscopic techniques for demonstrating viruses, fungi, and bacteria were discussed.

I discussed how diagnostic techniques were used in a large-scale evaluation of disease in natural gypsy moth populations. I pointed out that certain techniques must be modified when diagnosing a large number of insects in a limited time frame, and that one must compromise some degree of diagnostic detail in order to obtain numbers that can be subjected to rigorous statistical analyses.

Finally, R. A. Dicapua, associate professor of immunology at the University of Connecticut, discussed the potential of various immunological assays for detecting preclinical cases of insect virus disease in the field. He indicated that these could be valuable tools for the accurate prediction of future populations trends.

Headquarters of the Northeastern Forest Experiment Station are in Upper Darby, Pa. Field laboratories and research units are maintained at:

- Amherst, Massachusetts, in cooperation with the University of Massachusetts.
- Beltsville, Maryland.
- Berea, Kentucky, in cooperation with Berea College.
- Burlington, Vermont, in cooperation with the University of Vermont.
- Delaware, Ohio.
- Durham, New Hampshire, in cooperation with the University of New Hampshire.
- Hamden, Connecticut, in cooperation with Yale University.
- Kingston, Pennsylvania.
- Morgantown, West Virginia, in cooperation with West Virginia University, Morgantown.
- Orono, Maine, in cooperation with the University of Maine, Orono.
- Parsons, West Virginia.
- Pennington, New Jersey.
- Princeton, West Virginia.
- Syracuse, New York, in cooperation with the State University of New York College of Environmental Sciences and Forestry at Syracuse University, Syracuse.
- Warren, Pennsylvania.

Northeastern Forest Experiment Station.
1976. **Proceedings of the Eighth Annual Northeastern Forest Insect Work Conference.** Northeast. For. Exp. Stn., Upper Darby, Pa.
20 p., illus. (USDA For. Serv. Gen. Tech. Rep. NE-27)

A report on this conference, whose theme was "Techniques for Research, Development, and Application." It includes discussions of the pilot boll weevil eradication experiment; kairomones and their role in pest management; the gypsy moth research, development, and applications program; parasite evaluation and management; and field and laboratory identification of insect pathogens.

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by GEORGE R. TRIMBLE, Jr.

A History of the FERNOW EXPERIMENTAL FOREST and the PARSONS TIMBER AND WATERSHED LABORATORY

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ABSTRACT

THIS IS A HISTORY of the people and the research they have carried out on the Fernow Experimental Forest during the past 43 years. The beginning of U.S. Forest Service timber-management research in West Virginia dates back to 28 May 1934, when the Fernow Experimental Forest was established. In 1950, watershed-management research was begun, and now both are carried out—along with additional multiple-use projects—as responsibilities of the Parsons Timber and Watershed Laboratory. Except for the war years in the 1940s, an ever-intensifying program of research has been carried out at this location. In the initial years, the old Appalachian Forest Experiment Station directed the program of research; since 1948 the Northeastern Forest Experiment Station has been responsible for this work.

Key words: research history, Fernow Experimental Forest, timber and watershed management.

ACKNOWLEDGMENT

Many people contributed to the preparation of this history. Librarians of both the Northeastern and the Southeastern Stations searched the files for reports and publications. Staff people of the Parsons Timber and Watershed Laboratory took pictures and reviewed the manuscript. Special thanks are extended to Kathleen Hammack, who labored hard and efficiently in assembling historic material, arranging photographs, and preparing the manuscript.

COVER PHOTOS.—Top: this rugged forest land, where the Fernow Experimental Forest is located, is typical of the forested mountains in Appalachia.
Bottom: present headquarters of the Parsons Timber and Watershed Laboratory, a research facility of the Northeastern Forest Experiment Station, Forest Service, U. S. Department of Agriculture.

A History of the FERNOW EXPERIMENTAL FOREST and the PARSONS TIMBER AND WATERSHED LABORATORY

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The Author

GEORGE R. TRIMBLE, JR., retired 3 years ago after 38 years with the U.S. Forest Service, 20 of them working at the Parsons Timber and Watershed Laboratory in West Virginia. He received a B.S. degree in forestry at the University of Maine and began his working career on the White Mountain National Forest. He later transferred to the Northeastern Forest Experiment Station and did both watershed- and timber-management research throughout the Northeastern States. He is the author or co-author of more than 100 publications. In 1973, he was named West Virginia Forester of the Year by the West Virginia Wildlife Federation. In 1974, he received the Society of American Foresters, Allegheny Section, annual award for outstanding service to forestry.

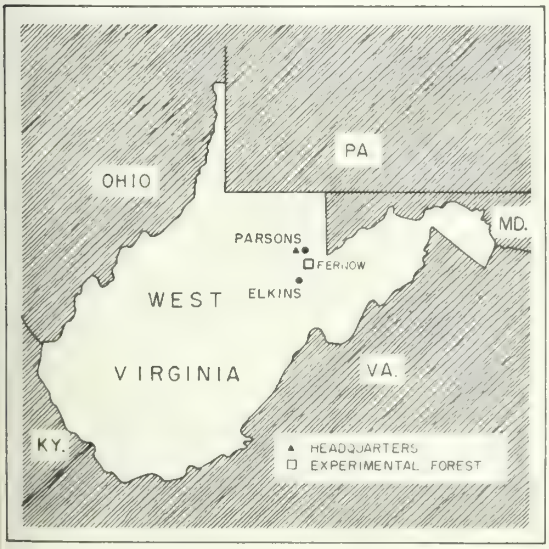
MANUSCRIPT RECEIVED FOR PUBLICATION 20 MAY 1976

The Beginning

THIS IS A HISTORY of the Fernow Experimental Forest and the Parsons Timber and Watershed Laboratory. The Fernow Forest is an outdoor research area where the Laboratory staff carry out most of their studies. It lies 3 miles southeast of Parsons, W. Va., and 25 miles from Elkins. The laboratory is located on the Parsons Nursery Bottom just east of Parsons.

Named in honor of Bernhard E. Fernow, the well-known German-born forester who pioneered forestry in the United States, the 3,640-acre Fernow Experimental Forest has played a significant role in forest management in the Appalachian Region for a third of a century. Research work was started here in the early 1930s under the direction of the Appalachian Forest Experiment Station, with headquarters in Asheville, N.C. During World War II, the program was shut down. In 1945, when the Forest Service reorganized its system of experiment stations, the Northeastern Forest Experiment Station (with headquarters now in Upper Darby, Pa.) was assigned responsibility for research work in this area. And in 1948 a new program of studies was started in West Virginia.

Location of the Fernow Experimental Forest.



Many people have had a hand in the work that has been carried out here. In writing this history, I have tried—where it seemed appropriate—to identify individuals involved in specific activities.

During its existence, from 1934 to the present, the Fernow research unit has had three different organic structures.

First, as an *experimental forest.* Under this setup, a junior forester or an assistant forester, who lived in the locality and was supported by a local staff, administered the development and maintenance work, carried out research supporting programs—such as inventories and plot establishment—and made routine measurements. Most of the research planning, study development, and analysis of results were done in the Experiment Station office in Asheville by project leaders in the various disciplines such as fire control, silviculture, and mensuration. These men often spent long stretches of time on the Experimental Forest. The Fernow research program was operated in this way during the tenure of the Appalachian Forest Experiment Station (later renamed Southeastern Forest Experiment Station).

After the research program was reactivated on the Fernow Forest in 1948, the unit was administered as a *research center,* much like a miniature experiment station, with a center leader who was responsible for all projects. Project leaders in each discipline answered to center leaders, and center leaders answered to the Station director.

In the service-wide reorganization of research in 1959, a new structure was adopted. The position of center leader was abolished. Now each project leader was responsible for his research work unit, and he looked to a division chief—who later became an assistant director—for direction. An administrative assistant was brought in to handle many of the administrative duties that the center leader formerly performed or assigned to other personnel in the organization.

Elk Lick Run Watershed before Establishment as Fernow Experimental Forest

Elk Lick Run watershed, most of which now encompasses the Fernow Experimental Forest—along with part of the Otter Creek drainage—was originally granted to Francis and William Deakon by the State of Virginia in 1788. Jonathan Arnold paid the Deakon heirs $4,000 for the land in 1856; later he handed the property down to his son, Thomas J. Arnold. In 1901, Thomas Arnold sold the timber rights on this property to C.S. Vasbinder, one of the owners of the Elk Lick Lumber Company, who paid $11.50 per acre for the timber rights.

Logging was started about 1903 and was completed by the end of 1911. There is no indication that any cutting took place in Elk Lick before 1903. A logging railroad was built to haul the logs to the mill—as was customary in those days. Skidding was done with horses and chutes or log slides. The logs from the Elk Lick Run area were sawed at the Elk Lick Lumber Company mill, located between Hambleton and Parsons.

Cutting was heavy but variable. In areas easily accessible to the railroad, the forest was clearcut of all sawtimber-size trees except culls; from less accessible areas, only the better stems of preferred species were taken.

This Arnold tract was the first purchase unit of the Monongahela National Forest. In 1911 R.C. Bryant made a preliminary report on the area for the Forest Service. He recommended purchase by the government. In 1912, W.A.

Elk Lick Run, which drains the Fernow Forest.

Hopson, forest examiner, made an evaluation of this tract for the government in which he recommended purchase of 7,136 acres at his appraised price of $5.54 per acre. In 1913, the National Forest Reservation Commission considered purchase of this land, but turned it down as being priced too high. Attempts to attain it at a lower price were not successful.

The following year, a lumberman, C.D. Cushing, was commissioned to examine this tract and report why these lands were priced higher than most cutover lands. He justified the price, and his opinion was backed up by William L. Hall, assistant forester, who examined the tract in August 1914. Hall emphasized the good soil, the excellent young growth, and the ready access to many wood-using plants. He urgently recommended purchase of this tract at the asking price of $5.50 per acre—$4.50 for the land and $1.00 for stumpage.

The Forest Service purchased the Arnold Tract on 26 November 1915 at this asking price. The area had been split up into a number of appraising units, and the portion that comprises the present experimental forest—or at least the major part of it—was appraised at $7.00 per acre. Mineral rights were reserved.

Little descriptive material is available about the area as it was before logging. C.A. Abell, who in 1933 wrote one of the reports upon which was based the establishment of the area as an experimental forest, had this to say about the original forest:

> On lower elevations, the forest was mainly hardwoods with hemlock in mixture along creek bottoms and north slopes. The higher ridges were covered with an excellent stand of spruce and hemlock, while in small patches on the tops of the mountains were pure spruce stands. The tract averaged 15 M board feet per acre.

No information about tree size was included in the volume estimate, nor was there any indication of the board-foot rule used to estimate the volume.

Some idea of the condition of the forest after logging can be obtained from Abell's report on the area about 20 years after the cutting. Abell apparently drew on older reports for this after-logging description:

> Non-merchantable timber lands comprise the entire acreage offered [for sale to the government]. This land has not been cut as close as many tracts in the region and a few hundred feet of beech, birch, and maple remain. This is either defective, rather inaccessible, or under 10 inches in diameter . . . . There have been no fires since logging started and good growth of chestnut, chestnut oak, and black oaks are coming in. On small areas good stands of chestnut poles, 6 to 8 inches were noted. The tract is in better condition than the majority of cut-over areas that will be offered in this section. Light logging and no fires have given the forest a good chance to build up and recovery will be rapid if fire is kept out.

The black oaks Abell mentioned were mostly *Quercus rubra* L. Though members of the black oak group, they usually are called northern red oak.

Although there is evidence of some past fires in the area, fire damage has been slight, probably because the area came under Forest Service protection so soon after the original cutting. A Forest Service protection unit that was organized in 1916 included the Arnold Tract.

It would seem that Abell in his report underestimated the quantity of sawtimber left after logging; or—more likely—the standards of merchantability were stricter then than now. In 1948, when the Fernow Forest was reactivated, many areas—especially upper hollows a long way from the old railroad grades—had heavy stands of merchantable old-growth timber, predominantly sugar maple.

In September 1931, L.I. Barrett and I.H. Sims of the Appalachian Forest Experiment Station examined four areas on the Monongahela National Forest for possibilities as experimental forests, among which was Elk Lick Run watershed. They recommended this watershed for several reasons, among which were: good variety of sites and types of timber, particularly yellow-poplar; stands older than most on the Monongahela; typical north-central West Virginia topography; and good accessibility. Their report was submitted on 16 September 1931.

On 7 November 1931, Arthur A. Wood (Monongahela National Forest supervisor), Webb Myers (State game protector at Parsons), and Jesse H. Buell (assistant silviculturist with the Appalachian Forest Experiment Station) examined the Elk Lick Run watershed. They, too, recommended that this area be developed as an experimental forest.

On 8 July 1932, the director of the Appalachian Station, E.H. Frothingham, wrote to Assistant Regional Forester R.M. Evans, suggesting that a line-plot survey be made in which timber and topographic data be noted and mapped, the outcome of this survey to be the basis for delineating the proposed experimental forest.

And in October and November 1932, Abell, his wife Mary S. Abell (herself a junior forester), V.E. Hicks, and W.E. Hodges inventoried the area and made a type map. Abell, chief-of-party, wrote up the notes on the survey and submitted them on 8 April 1933. He also made a report justifying the establishment of the experimental forest on the basis of the investigative possibilities there.

Eventually a recommendation went to the "Forester"—at that time the head of the U.S. Forest Service was called "Forester", not "Chief"—to set aside 3,640 acres in Elk Lick Run drainage as the Fernow Experimental Forest, to be administered under the direction of the Appalachian Forest Experiment Station. Forester F.A. Silcox signed the order establishing the Fernow Forest on 28 May 1934.

Fernow Experimental Forest as a Unit of the Appalachian Forest Experiment Station

The research unit that developed the program on the Fernow Forest during the period when the Appalachian Forest Experiment Station was in charge was known as a "Branch Station".

In the first 2 years after the Fernow Forest was set up, development work went on apace, aided by the Civilian Conservation Corps and the Civil Works Administration; a CCC camp on the Parsons Nursery Bottom supplied labor for years. Eight miles of road were built and another 5 miles started; much of this mileage was built on the old railroad grade that ran along Elk Lick Run.

The exterior boundary of the forest was marked by a 15-foot cleared firebreak. Narrower interior firebreaks were cleared along ridges, dividing the area into 25 compartments. An additional 10½ miles of foot trail was prepared. A combination log toolhouse and blacksmith shop was constructed beside the main Elk Lick road about 1/2 mile in from the lower boundary. Because open grazing was a way of life in West Virginia at that time, 1½ miles of woven wire fence was put up on the north boundary to prevent stock from drifting into the forest.

Forest headquarters buildings were constructed on the Parsons Nursery Bottom; they included a bunk house, a dwelling, and a combination work shop and garage. While this construction work was going on, the foresters had been busy. A topographic map of the Fernow Forest was prepared, with 40-foot contour intervals. On this map were indicated the locations of stakes marking the centers of about 800 1/4-acre plots from which the original cruise of 1932 had been made and a type map developed.

The only research work in progress as of March 1936 was a set of experimentally burned plots established by the Station's fire-damage project in 1935.

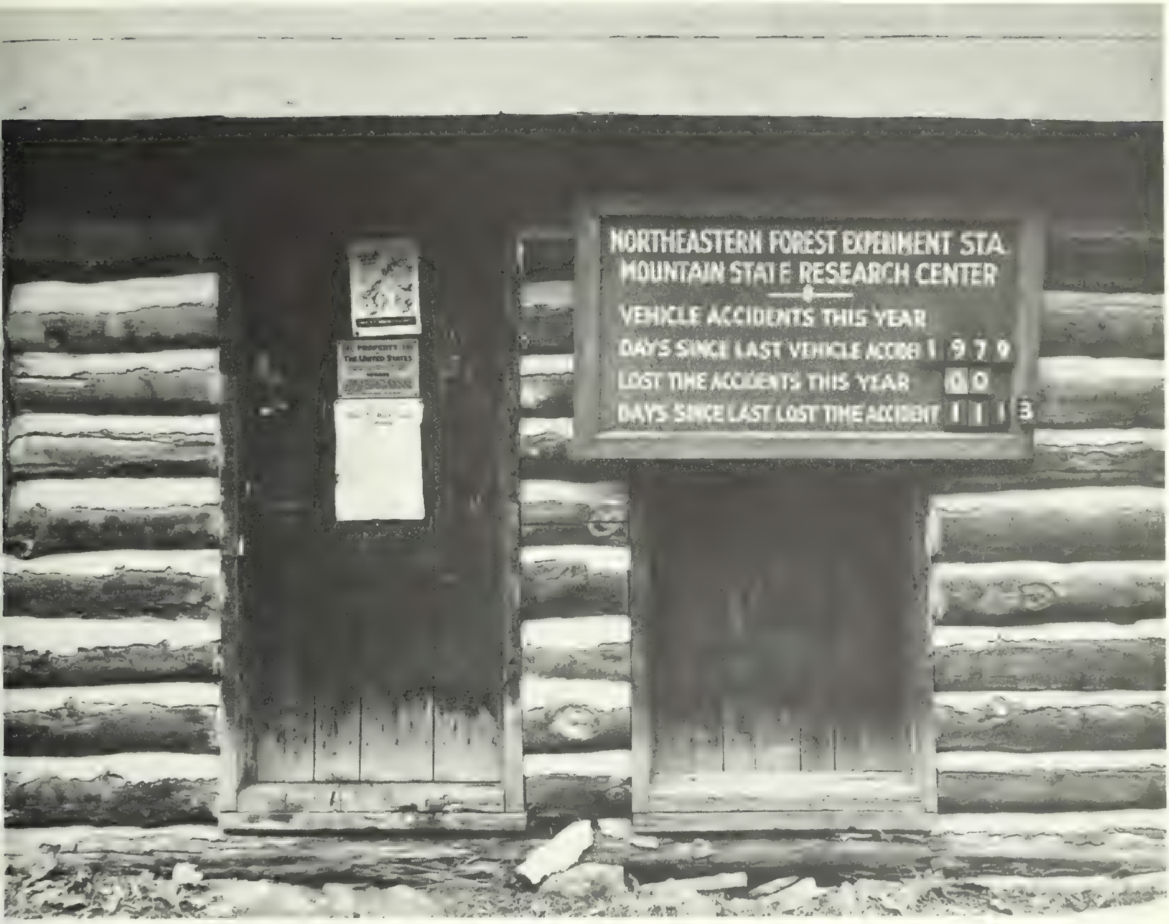
A water-supply reservoir for the town of Parsons was constructed on the Fernow Forest between 1934 and 1936 on a special-use permit from the Monongahela National Forest. Although it was not a research project, construction of this reservoir affected the research done above it, in that special care had to be taken so as not to damage the water supply.

In 1936, the personnel situation was as follows: C.A. Abell was silviculturist-in-charge at the Fernow Experimental Forest; Joseph O. Kirchner was regional forester of Region 7; Arthur A. Wood was supervisor of the Monongahela National Forest; Ralph Smoot was Cheat District ranger (he took over from Don Gaudineer in April 1936); and D.A. ("Sandy") Oliver was nurseryman at the Parsons Nursery.

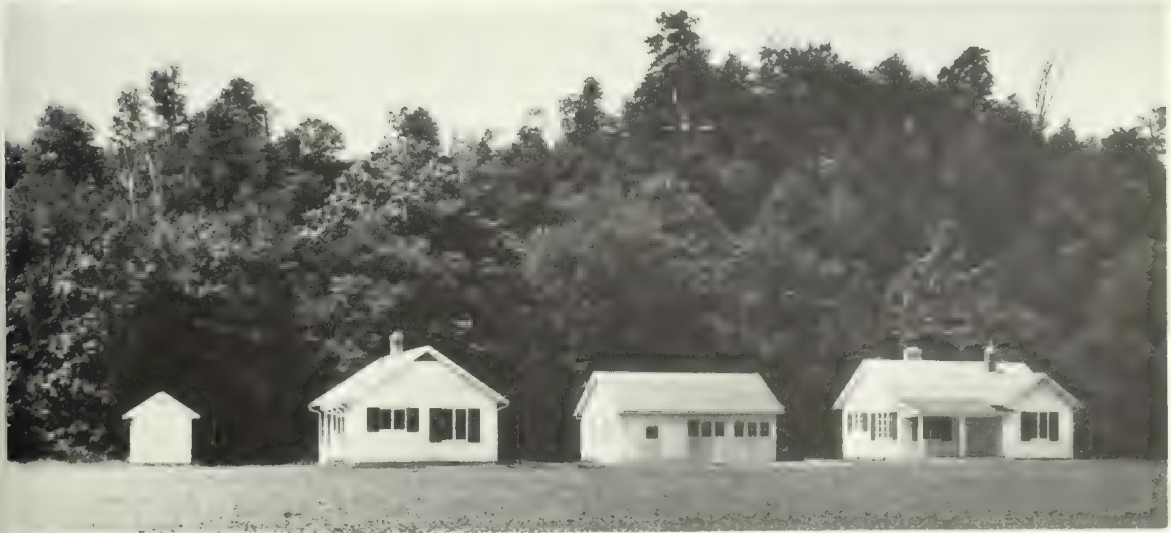
From late 1936 on, the pace of development of the physical plant slowed, but the research program was stepped up.

Jesse Buell established an extensive network of crop-tree-release study plots in the Appalachian area, some of them on the Fernow Experimental Forest. In 1939, Buell established a thinning study in second-growth yellow poplar on the Fernow Forest, and the effects on a wide range of tree and stand characteristics were related to two kinds and two degrees of thinning. W.G. Wahlenberg later took over this study and published the results in two articles in the JOURNAL OF FORESTRY.

By 1941, Leon Minckler had established a number of reforestation study plots in the cutover and burned-over spruce lands on the


NORTHEASTERN FOREST EXPERIMENT STA.
MOUNTAIN STATE RESEARCH CENTER
VEHICLE ACCIDENTS THIS YEAR
DAYS SINCE LAST VEHICLE ACCIDE 1 9 7 9
LOST TIME ACCIDENTS THIS YEAR 0 0
DAYS SINCE LAST LOST TIME ACCIDENT 1 1 1 3

The old log toolshed-blacksmith shop, first building on the Fernow Experimental Forest.



Early headquarters buildings—bunkhouse, dwelling, and garage—in the mid 1930s.

Monongahela National Forest (as well as on the Pisgah National Forest in North Carolina). Minckler published early results of this work, and in 1954 a final report was published on the results of this study in West Virginia by Thomas G. Clark, who at that time was a member of the Northeastern Forest Experiment Station.

In 1941, as the United States geared up for the war effort, reduction of funds forced the termination of work on the Fernow Forest, except for remeasurements of the spruce planting and yellow-poplar thinning plots. The buildings were boarded up, not to be opened again until after World War II.

Fernow Forest under the Northeastern Forest Experiment Station

After the war, in 1948, the Northeastern Forest Experiment Station established a branch unit, first known as the Mountain State Research Center, in Elkins, W. Va. Later the name was changed to the Elkins Research Center, a title that was retained until 1964, when the headquarters was moved to Parsons and the name was changed again, this time to the Parsons Timber and Watershed Laboratory. Although the headquarters were in the Forestry Building in Elkins from 1948 until 1964, most of the activity took place on the Fernow Experimental Forest, and most of the personnel lived in Parsons. Until an office building was erected in 1954, the bunkhouse was used as the Fernow office; it also housed official visitors. Some member of the staff, with family, has always occupied the residence on the nursery bottom.

The transition from the Appalachian to the Northeastern Forest Experiment Station was facilitated by the efforts of W.G. Wallenberg and W.T. Doolittle of the Appalachian Station. These two men worked closely with Northeastern personnel in completing old studies and in transferring records.

PERSONNEL

The Center started operations in 1948 with five people: Sidney Weitzman, center leader; Carl J. Holcomb, timber-management project leader; Thomas G. Clark, timber-management researcher; Carl R. Barr, logging superintendent; and Geraldine L. Trickett, clerk-typist.

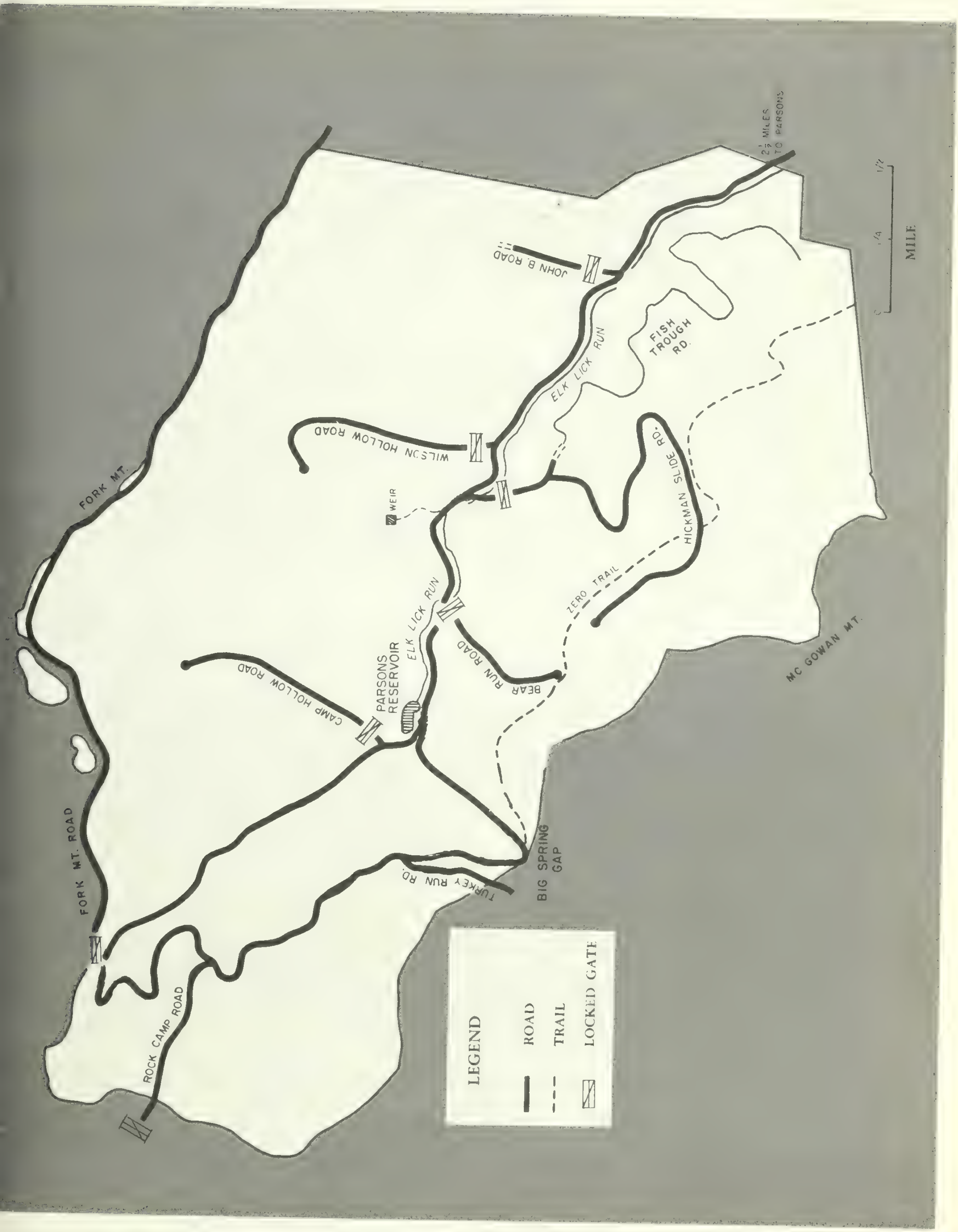
During the 28 years of its existence, the research unit has expanded in size and grown in complexity. Including the people in the two projects—timber- and watershed-management research—and 3 full-time employees in administrative services, a total of 21 regular employees and 4 part-time and temporary employees now work at the Parsons Timber and Watershed Laboratory. From 1948 until now, more than 50 permanent Forest Service employees have worked in the organization. Temporary and part-time employees for the same period add up to about twice this number.

The increase in diversity of research personnel over the years is a measure of the specialization of the program. Initially, all the professional researchers were foresters; now the group also includes soil scientists and hydrologists. With the increased diversity of the professional staff has come diversity of the technician staff. For example, today the timber-management research project supports a statistical assistant, Kathleen P. Hammack; and the watershed-management project keeps a water-quality analyst, James D. Phillips, busy full time.

DEVELOPMENT OF PHYSICAL FACILITIES

The Fernow Forest road system, well started by the Appalachian Forest Experiment Station, has been added to and improved upon over the years. The Rock Camp spur was constructed in 1950, and the Camp Hollow road was built the following year. The Bear Run and Hickman Slide roads were built in 1953. During the next 12 years, four more roads were added to the system: Wilson Hollow, John B. Hollow, Lower Fish Trough spur, and Upper Fish Trough spur. The last road to be built was the Fork Mountain spur. All these are National Forest System roads, and most of them have been gravelled. Together they add up to about 25 miles of road.

In 1954, a new office building was completed on the nursery bottom; and in 1957, a combination garage, storage building, and workshop was

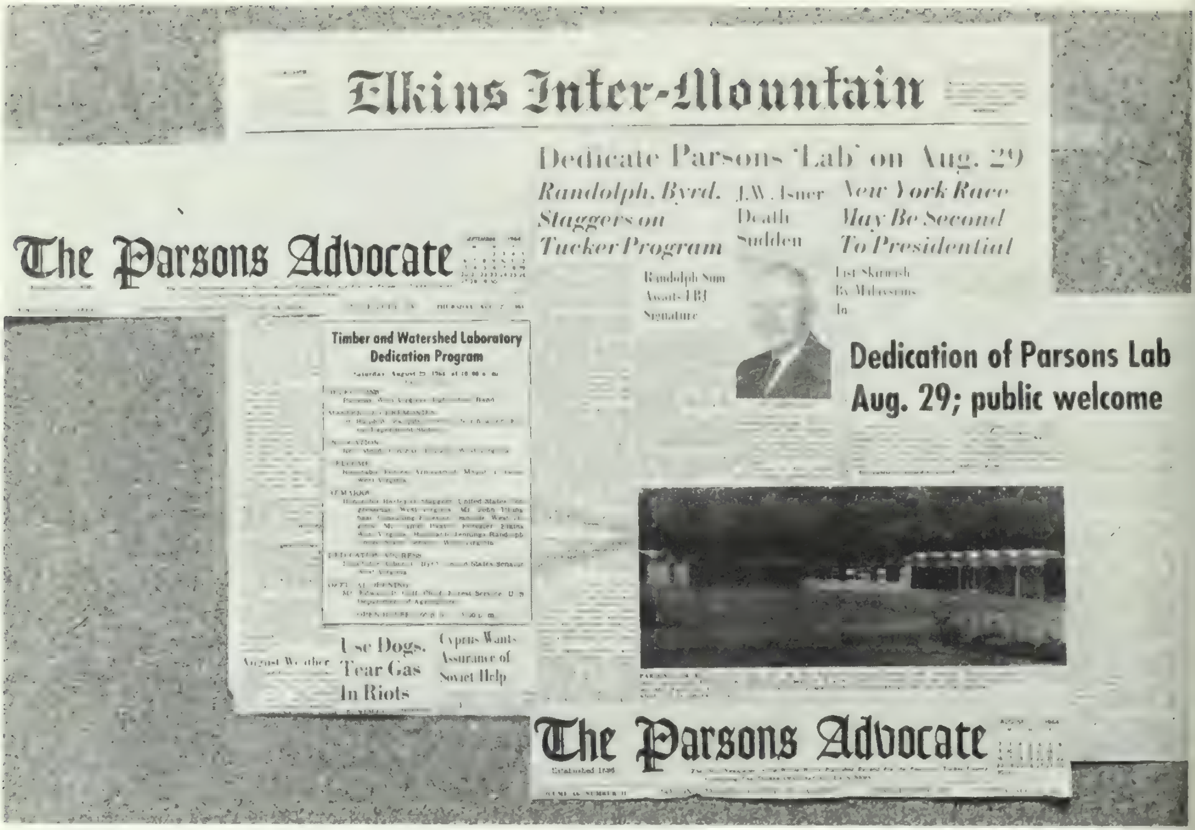

FORK MT.
FORK MT. ROAD
ROCK CAMP ROAD
TURKEY RUN RD.
BIG SPRING GAP
CAMP HOLLOW ROAD
PARSONS RESERVOIR
ELK LICK RUN
BEAR RUN ROAD
ZERO TRAIL
HICKMAN SLIDE RD.
WEIR
WILSON HOLLOW ROAD
ELK LICK RUN
FISH TROUGH RD.
JOHN B. ROAD
2 1/2 MILES TO PARSONS
MC GOWAN MT.
0
1/4
1/2
MILE
LEGEND
ROAD
TRAIL
LOCKED GATE

The first office building was erected in 1954, the garage in 1957.

This tractor repair shed was erected in 1962, to replace the old log toolshed.

The present Timber and Watershed Laboratory, erected in 1964, as it appears today. A greenhouse (at left) is the latest building on the headquarters site.

U. S. Senator Robert C. Byrd of West Virginia keynoted the dedication of the Parsons Timber and Watershed Laboratory on August 29, 1964



Elkins Inter-Mountain

Dedicate Parsons 'Lab' on Aug. 29

Randolph, Byrd, Staggers on Tucker Program

J.W. Asner Death Sudden

New York Race May Be Second To Presidential

Randolph Sum Awaits LBJ Signature

Last Skirmish By Malaysians In

The Parsons Advocate

Timber and Watershed Laboratory Dedication Program

Use Dogs, Tear Gas In Riots

Cyprus Wants Assurance of Soviet Help

August Weather

Dedication of Parsons Lab Aug. 29; public welcome

The Parsons Advocate

constructed behind it. A concrete record-storage vault was also built.

In 1962, a tractor-repair shed, which combined workshop and storage space, was erected on the Fernow Forest across from the entrance to Hickman Slide hollow. This replaced the old log-cabin workshop, which had been torn down. In 1972, a storage building was erected a little farther up Elk Lick to house watershed-research equipment and materials.

In 1964, a modern laboratory and office building was erected on the nursery bottom. This building provided much-needed facilities for an intensified program of research. For the first time, the unit had adequate office space and laboratory equipment.

Many people had a hand in getting this Laboratory built in Parsons. Prominent among them were Senator Robert C. Byrd of West Virginia; V. L. Harper, Deputy to the Chief in charge of Forest Service research; and Ralph W. Marquis, Director of the Northeastern Forest Experiment Station. The Laboratory was dedicated on 29 August 1964. Carter B. Gibbs, then a timber-management researcher with the Parsons Timber and Watershed Laboratory and now an assistant director at the North Central Forest Experiment Station, master-minded the dedication program.

The last building constructed on the Parsons Nursery Bottom was a greenhouse erected in April 1976.

PROGRAM OF RESEARCH

Almost from the beginning, two lines of investigation have been carried out on the Fernow Forest: timber-management research and watershed-management research. It was recognized early that the two are closely related: manipulating the forest for timber-management purposes affects watershed relations and vice versa. For this reason, many of the large-area studies were conducted jointly by scientists in the two projects, with resultant gains in more widely applicable results as well as increased fiscal efficiency.

During the first 2 years, center personnel were concerned largely with making a timber inventory of the Fernow Forest, writing study work plans, selecting compartments for testing silvicultural systems on a large scale, hiring and training a logging crew, and building weirs on five watersheds. During this period, Sidney Weitzman prepared a detailed and comprehensive program analysis that served as a guideline for the research program. Toward the end of this period, cutting practice studies were begun. And George R. Trimble, Jr., was transferred from Upper Darby to develop the watershed-research program.

By mid-1951, the research program was well under way, and the basic pattern of research was established for both projects. A system of compartment studies of a long-range nature was combined with short-range studies designed to solve special problems or to determine the hows and whys of the gross effects measured on the compartments. To some extent, this is still the pattern of research today, especially in timber management; but the trend has been to put more emphasis on studies of a short-range nature and on research in depth.

The following are the main research contributions in timber and watershed management that have come from the Parsons unit in the period 1948 to the present.

Timber-Management Research

The present mission of the timber-management-research project is to learn how to establish, culture, and harvest high-quality central Appalachian hardwoods, in a way that is compatible with increasing public demand for other uses of the forest—multiple-use. Although the wording of the mission has been changed several times over the years, the research objectives have remained essentially the same.

During the first years of research, the Fernow

This 65-year-old even-age stand on the Fernow Forest is under intensive management.

In this stand with sugar maple understory, a light selection cutting was made.

Forest logging crew pioneered a number of innovations in logging techniques and skidroad layout. Carl R. Barr and his loggers were the first in Appalachia to use tree-length skidding in combination with a carefully designed system of skidroads. Because it had a favorable cost record, this skidding system was adopted by many Appalachian loggers.

Reproduction studies have always been an important part of our research program. They are a part of every large-area study, and regeneration has been and is the subject of many special studies. We have found that clearcutting results in more reproduction, faster-growing reproduction, a greater variety of species, a higher proportion of high-value intolerants, and a higher proportion of stump sprouts than does selection cutting.

Overall, it appears that any cutting heavy enough to be economically feasible is heavy enough to result in adequate numbers of reproduction stems to regenerate the stand. We have discovered that black cherry seed lies dormant in the forest floor at least 3 years, and we have found that dormant-season logging favors yellow-poplar reproduction more than spring and summer logging does.

For a number of years, we have been trying to find better methods to artificially regenerate oak. A big problem is that young oak stems grow so slowly the first few years that they succumb to faster-growing competition. Among the methods being tested are application of fertilizers, top-pruning, outplanting of containerized stock, outplanting nursery stock of several age classes, and selection of stock that in the nursery bed displayed more than one flush of annual height growth. George W. Wendel, assisted by Robert L. Rosier, is handling this program.

The results of three site-quality studies have been published. They relate site index of the upland oaks to soil and topographic features within defined physiographic provinces. This permits site identification without recourse to measurement on standing trees. The early establishment of a site-identifying method by Trimble and Weitzman has facilitated silvicultural research because site quality is one of the main factors determining the growth rates of stands and trees and the species composition and development of reproduction. Moreover, since the establishment of oak site index as a valid indicator of forest response to treatment, it has been used widely by practicing foresters in the central Appalachians. Two of the four site-quality studies made to date were made by Harry W. Yawney, who later transferred to the Station's laboratory at Burlington, Vt.

A sapling stand that developed after clearcutting.

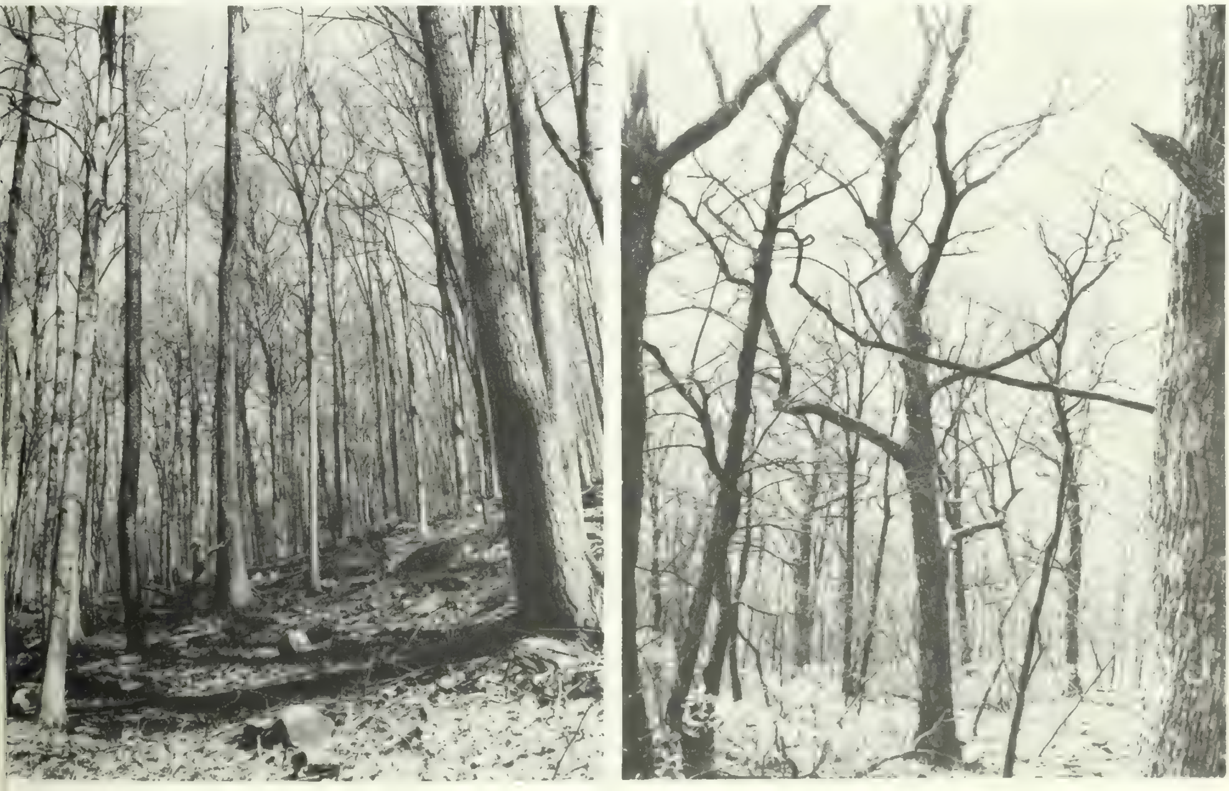
Growth studies have been an important part of the research program from the beginning. From individual-tree growth studies we have determined the dbh growth rates of important species, and we have related tree growth to site quality and crown position. Stand growth studies, made on large plots and on compartments, have provided growth data for stands managed by individual-tree-selection practices and by some levels of diameter-limit cutting; and we have related these growth rates to site quality. Studies underway are designed to yield stand-growth information for areas of even-aged management, areas cut by selection systems based on different levels of financial maturity, and areas where small patch cutting or group selection is being practiced.

Only one study has been made to relate stand yield to stand density. This study, set up in 1954 by Sidney Weitzman and Robert Lindahl, was made on areas of site quality (in terms of oak site index) of 85 and 63 feet. The results showed that cubic-foot growth over a 10-year period was not affected by after-cutting ranges of density (in trees over 5.0 inches dbh) between 60 and 100 square feet basal area on the better site, and between 45 and 75 feet on the poorer site. However, on the 85-foot site, board-foot growth was significantly less on the plots of 60-square-foot density. But board-foot growth on the 63-foot site was unaffected by residual density within the range tested.

A series of precommercial crop-tree-release experiments on large areas of young even-aged hardwoods is providing valuable information. We have learned that only codominant and dominant trees are good risks for release, and then only if they are at least 15 feet tall, tall enough to stay ahead of sprout growth from stumps of competing trees cut in the release operation. Where grapevines are a serious problem, released stems should be 25 feet tall, or the grapevines will grow back up in them.

Although it was at no time a major effort, we

On the left, a stand of timber growing on an excellent site. On the right, a stand of timber growing on a very poor site. Both stands are the same age.



A red oak sprout clump at 10 years. Sprouting is under intensive study on the Fernow Experimental Forest.

have made a number of studies on how to control culls and noxious plants. Recently, considerable pioneering work has been done on grapevine control.

Grapevines may be the biggest cultural-treatment problem on good and better sites in the central Appalachians when even-aged practices are used. Grapevine seeds can germinate after lying dormant many years on the forest floor, but it is the fast-growing sprouts from cut vines that give the most trouble in young clearcut stands. Unless controlled, grapevines may destroy or severely damage as much as three-fourths of the new tree stems. We have found that the intolerant grapevines will die if cut off under the old stand 4 years before the overstory is harvested. Their demise is caused by the shading effect of the overstory.

A number of economic evaluations of forestry returns have been made by laboratory personnel in cooperation with economists from other units. G. R. Trimble, Jr., worked with Station economists in publishing four evaluations of

Grapevines are a source of serious damage in hardwood stands on good sites.

forestry costs and returns based on large-area cutting on the Fernow Forest. Other research results in the economic area that were published include: development of financial-maturity information for half a dozen important hardwood species; a field-tested method of selection marking based on financial maturity; and cost figures for a wide range of forestry operations such as tree-marking, cull-killing, and foliar-spraying to control undesirable understories.

Our genetics research has been limited to clonal testing of hybrid poplars *(Populus)* and to provenance and progeny studies involving white pine, sugar maple, and—very recently—white ash and black walnut. The hybrid poplar research identified seven clones that are very high-yielding in this area. In all of this work except the white pine tests, the Parsons unit has been cooperating with other groups that have had primary responsibility for conducting the studies.

Fertilization studies were started by Luther R. Auchmoody, soil scientist, who arrived in 1966. Auchmoody laid the groundwork for forest-nutrition research before he was replaced by Neil Lamson. To date, the work has been largely an attempt to determine what nutrient deficiencies exist in the major forest soils, as indicated by growth response of the important hardwood species.

Studies have been carried out in search of an acceptable method of converting poor-site hardwood stands to white pine. To date, underplanting several years before the hardwood

Broadcast application of fertilizer to surface of a study plot in a young stand of yellow-poplar.

White pine provenance test on an area of low site quality for hardwoods.

canopy is removed seems to be the most promising procedure, more promising than direct-seeding either before or after hardwood removal and better than planting after the overstory is harvested.

We recognize that the amount of profit in hardwood management depends heavily on the quality of the lumber that can be cut from the wood produced. In all large-area comparisons of cutting practices, we have incorporated measurements of log grade and stand defect. It has been established through studies on the Fernow Forest that intensive practice of selection silviculture on good sites produces sawtimber yields in which at least 60 percent of the harvested volume is composed of log-grade 1 and 2 material. Under the same type of silvicultural practice, defective material in the stand stabilized at about 4 percent.

Information that has been published defines for the more important species the trend of butt-log-grade improvement with increase in tree diameter.

It has been shown that understory sugar maple saplings show an improvement in stem form with an increase in height where selection cutting provides some overhead release.

It has been established that stump-sprouting after clearcutting produces a larger number of good-quality stems than has generally been believed.

Cull trees have been identified by condition classes: (1) those likely to die soon, and (2) those that will live and compete with other trees.

A number of studies produced information that permitted rating species by susceptibility to epicormic branching. And relationships have been established between epicormic branching and crown class, height on tree bole, and degree of release.

The type of study that has been emphasized most on the Fernow Forest and has taken up more time than any other has been large-area comparisons of different silvicultural systems. Because long-term comprehensive studies of both even-age and uneven-age systems have been under study for many years, considerable information was available for use in the Monongahela controversy that triggered a revision of the Organic Act of 1897. Because research results could be substantiated by on-the-ground observation of large areas treated by a wide range of practices, many Fernow data were highly effective in convincing legislators and other influential people of the general soundness of the foresters' viewpoints. Although these studies have not yet produced all the definitive results that can be expected of them, they have pointed out many strong and weak points of the two general methods of management practiced in Appalachian hardwoods—even-age versus uneven-age.

Watershed-Management Research

The present mission of the watershed-management research project is "to determine the effects of forest-resource management and use on quality, yield, and timing of streamflow; and develop methods for improving water yield and timing of forest streams without detriment to water quality".

Because research emphasis has changed with the years, I have divided this discussion into three parts to reflect this change. They correspond roughly to the tenures of the three watershed project leaders who have worked in the Parsons unit: 1950-54, G. R. Trimble, Jr.; 1955-67, Kenneth G. Reinhart; and 1968-present, James H. Patric.

Weir, stilling basin, and gage house on a study watershed.

1950-54

During this period, weirs were built in five watersheds, runoff-measuring and weather-recording equipment was installed, and calibration was begun. It was during the first bustle of instrumentation that Burley D. Fridley, watershed technician, demonstrated the talents that were later to earn him wide recognition—a master touch for installing and maintaining equipment used in hydrologic research.

In addition to working on the gaging study, the researchers spent many months defining the problem of skidtrail and logging-road erosion and learning how to control it—and in determining ways to keep the eroded soil out of streams. Fifteen years later, James Kochenderfer built on this information and authored a comprehensive paper on erosion control on logging roads.

It was also during this period that a study was made that showed the effect of a hardwood tree canopy in reducing the intensity of rainfall at the ground level.

1955-67

This 12-year period of watershed research at Parsons encompassed the end of the calibration period for the original five gaged watersheds and included their treatment period; it also saw the establishment of four more gaged areas and the treatment of two of them; and foremost of all, it was a time of streamflow analysis based on gaging records. Ken Reinhart, and the other men who came and went in the project during

A microclimate station on the Fernow Forest.

this period, did an outstanding job of analysis and reporting.

On the five original watersheds, four levels of cutting (one watershed was a control) showed streamflow increase to be roughly proportional to the amount of timber cut. The rate of return to pretreatment streamflow conditions also varied with the severity of treatment, less than a year being needed after the lightest cutting and a little more than 5 years required for the commercial clearcut area, where 85 percent of the cubic-foot volume was removed.

The results of this gaging study also indicated—and these findings were substantiated by later work—that road location and management, not degree of cutting, control sedimentation during and after logging. As with streamflow, the rate of sedimentation returned to pretreatment conditions rapidly, even in watersheds where road management had been very bad. This illustrated the influence of the rapid recovery of vegetation that is typical of the central Appalachians.

Of great importance, and creating considerable surprise, was the discovery that water increases from cutting were limited mostly to the growing season, when they were most needed and least likely to cause flood risk.

During this time of intensive involvement with gaging studies, the staff was busy also with other research, much of it concerned with reporting on analysis techniques and on the development of measuring equipment. Reinhart wrote a manual with Robert Pierce (now stationed at Hubbard Brook in New Hampshire) on the construction and use of stream-gaging stations in watershed research; this was published as a Department of Agriculture Handbook. Other developments of an inventive nature included a simple sediment filter for small streams, automatic devices to take water samples and raise trash screens at weirs, and a method of evaluating the effect of stones when making soil-moisture measurements.

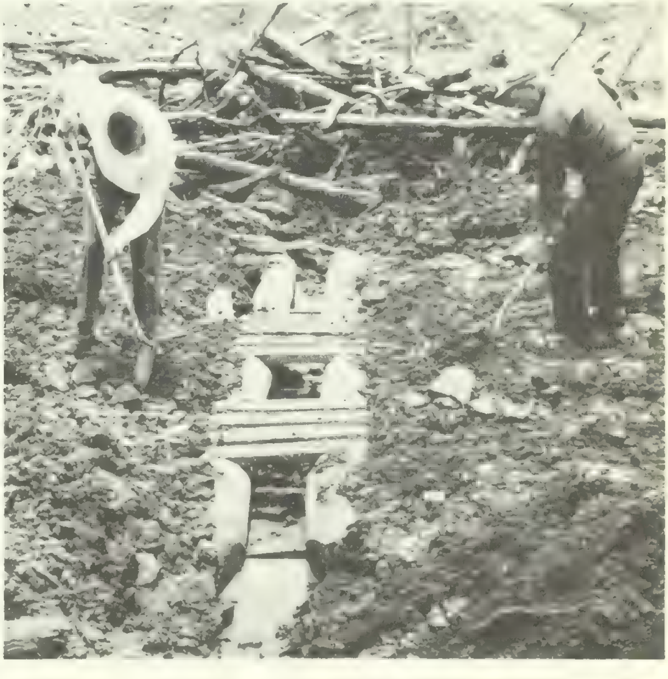
In the early 1960s, James W. Hornbeck installed sophisticated weather-recording equipment, which he used to accumulate data for developing a radiant-energy budget for clearcut and forested sites in West Virginia.

This was a period of great interest in watershed relationships by many organizations and agencies and by the general public. Because of this, our watershed scientists were in great demand for talks and reports.

A weather-observation tower on an experimental watershed.

Bulldozing a water bar. Careful designing of skid roads was an important feature of watershed research on the Forest.

Installing an open-top culvert, one of the devices to control erosion on logging roads.



1968-Present

This was a period of research expansion and diversification, a trend that was facilitated by the increase in professional staff from three to four men, one of whom, Gerald Aubertin, was well trained in soil and water chemistry. The new project leader, James Patric, had the diverse background to lead an expanded program, having participated in watershed research in North Carolina, California, and Alaska.

A clearcut watershed where both timber and watershed studies are being carried out.

Killing low vegetation with a mistblown herbicide on an area where transpiration is being studied.

The late 1960s witnessed decreased interest in amounts of water produced on forest land, and increased interest in its quality. Only two studies concerned primarily with water yield have been carried out since 1970. In the first of these, the upper half of one watershed and the lower half of another had been clearcut in 1963; all vegetation was killed with herbicides for the next 3 years. In 1966, the remaining forested halves also were clearcut, and both watersheds were treated with herbicides *in toto* for 3 more years. Because timber on both watersheds had been removed on carefully designed and managed roads, there was no evidence of accelerated soil erosion or of sedimentation in either watershed. Water yields were about 10 inches greater after cutting than before, but the excess dropped to 7 inches 2 years after we ceased applying herbicides.

We discontinued annual use of herbicides on these two watersheds in 1970. Since then, close observation of biomass on one of the watersheds is providing a record of hardwood revegetation. Norway spruce was planted in 1972 on the other watershed to measure the transpiration difference between conifers and hardwoods. This watershed was sprayed with 2,4,5-T in 1975 to release the spruce from overtopping hardwoods. Logan Norris' project at the Pacific Northwest Forest and Range Experiment Station provided funding and analytical facilities for a full-scale test of herbicide effects on vegetation, soil, water, and small-mammal populations.

Hydrologic record-keeping for two openland watersheds begun in 1957 was discontinued in 1971. These watersheds had been reverting from farmland to forest since abandonment in the 1930s. Careful analysis of the hydrologic data indicated that observation had begun too late in the reversion process to demonstrate measurable effects of reforestation on the quantity or quality of streamflow. This study did show that, at least under the conditions extant, abandoned farm lands recover hydrologically very well naturally.

Several studies, begun early in the 1970s, dealt with water quality. On one watershed, water-quality analyses, before and after the timber was clearcut, refuted at least for this area the widely-held belief that clearcutting diminishes the productive capability of forest land by accelerating the loss of soil fertility through streamflow. No appreciable increase in the outflow of nutrients was found.

Helicopter application of urea to an 80-acre watershed increased the nitrate content of the stream, but not enough to exceed public health standards. Analyses of data from several follow-up studies designed to further test the effects of other timber-harvesting and fertilization measures on water quality are incomplete.

Another widespread belief—that an unvarying supply of virtually pure water is assured by severe curtailment of timber harvesting—is countered by observing water quality from catchments only minimally influenced by human activity. Thus, variation in chemical and physical properties of the stream draining the Fernow control watershed demonstrates some natural fluctuation in quality of water from a catchment protected from timber harvesting for 65 years. Other studies, in close collaboration with Monongahela National Forest hydrologists, are adding much understanding of this natural variation.

Chemical properties of precipitation, particularly its acidity, not only influence chemical properties of streams, but also provide a frequently overlooked source of plant nutrients to forest soils. Precipitation chemistry is being measured on the Monongahela National Forest as well as on the Fernow Forest.

Recent technological advances have contributed greatly to our efforts to understand how water moves from the atmosphere, through forest soil and rock, to streams. By 1970, most forest hydrologists had concluded that surface runoff or overland flow has little to do with this movement. Development of the neutron moderation method permitted rapid, repetitive, and nondestructive sampling of soil moisture, helping greatly to enhance our understanding of water movement through forest soil. Under the leadership of Charles Troendle, the continuing effort to understand stream generation on forest land has progressed from investigation on crudely instrumented plots to heavily automated observation over entire small watersheds. Now our understanding of watershed processes and computer processing is sufficiently advanced that we can begin the mathematical modeling of baseflow as well as stormflow from properly instrumented watersheds.

SPECIAL ACTIVITIES AND UNIQUE ASPECTS OF THE LABORATORY'S PROGRAM

Logging Crew

Because we control the logging crew that does the research cutting on the Fernow Forest, we are able to get treatments made how and when we want. We exercise this control by hiring and supervising the men and by owning the logging equipment. We do this through a cooperative agreement with a private sawmill operator who contracts for the timber we cut. He reimburses us for the wages paid to the loggers and for the cost of equipment. Because the Fernow Forest is part of the Monongahela National Forest, he also pays appraised stumpage to the Treasury of the United States for the timber. In this way, we finance our research cuttings, except when small products are involved, such as pulpwood and charcoal wood. To harvest them, we sell stumpage.

From 1949 until 1974, Woodrow Price was our cooperator; since then Elmer Mullenax has been.

Another advantage derived from close control of the logging crew is that we are able to carry out studies in timber-harvesting methods, road layout, and equipment use. The loggers are available also for transfer to the research payroll when they are needed for use on jobs such as weir maintenance and timber-stand-improvement work.

Still another advantage of this arrangement is the practical training the researchers get through association with a real logging operation. This association undoubtedly has helped the foresters set timber-management-research priorities on a more realistic basis.

From 1949 until the present—the period of logging—we have harvested 17,600,000 board feet of sawtimber (International 1/4-inch kerf rule), and 5,600 cords of small products from the Fernow Forest. From the stumpage paid for this wood, 25 percent goes to the county for roads and schools—a very welcome income for them.

In the early days of logging, horses and oxen were used to skid logs out to the landing.

Felling a tree the old way, with a two-man crosscut saw.

Moving logs on the deck the old hard way, with peavy and man-muscle.

In the early days of logging in West Virginia, logging railroads were built to haul logs from the forest to the mill, and some of the present roads on the Fernow Forest are built on the old railroad grades. This Shay steam locomotive and its load of logs are typical of early logging.

An improvement over the backbreaking crosscut saw: a two-man gasoline powered chainsaw.

Felling timber the modern way, with a one-man chainsaw.

Skidding logs with a tractor on the Fernow Forest. The tree-length skidding pioneered on the Forest has been adopted by many Appalachian loggers.

Bucking tree lengths into logs on the deck.

Loading a truck the modern way with a loader.

Advisory Committee

In early 1948, station director V.L. Harper asked the members of the forest research committee of the West Virginia Forest Council (an organization now defunct) to act also as an advisory committee to the Mountain State Research Center. They agreed. The members of this first advisory committee were: W.C. Percival, head of the Division of Forestry at West Virginia University—chairman; W. B. Sayers, state forester; Arch Boyce, landowner; John Tillinghast, consulting forester; A.S. Wilson, vice-president and general manager of the Boone County Coal Corporation; and Arthur A. Wood, supervisor of the Monongahela National Forest. From this beginning, the Committee was expanded gradually over the years.

Until 1973, this group met annually with the Laboratory staff to review the research program. At this time the Forest Service discontinued formal advisory committees in favor of an *ad hoc* committee approach for soliciting advice.

At the time of the last meeting of the committee, the following were members: John Adams, Jr., forester, Western Maryland Railroad; Robert Schirck, timber staff officer, Monongahela National Forest; Tunis J. Lyon, chief of forest management, state of Maryland; Lester D. McClung, state forester of West Virginia; Raymond Menendez, fishery biologist, West Virginia Department of Natural Resources; Wilmer A. Stanley, manager, Beckley Water Company; John Tillinghast, consulting forester; R. P. True, professor of plant pathology, West Virginia University; David White, head of Division of Forestry, West Virginia University; and John B. Genys, Natural Resources Institute, University of Maryland.

Throughout the years, the advisory committee has functioned as a source of ideas, a sounding board, and a bulwark of support.

Meeting of the research unit's Advisory Committee members and guests in 1954.

Cooperative Studies

Cooperative studies have been part of the program from the beginning. The first cooperative research was with the West Virginia Department of Natural Resources—a study of the effect on deer browse of a range of cutting practices. Clay Smith (then a forest researcher and now timber-management project leader at the Laboratory) and Jack Cromer (deer biologist with the West Virginia Department of Natural Resources) published the results of the study, which, in essence, indicated that any cutting heavy enough to be economically feasible was heavy enough to produce sufficient browse to support a deer herd of reasonable size.

A number of studies have been made in cooperation with the Monongahela National Forest. The Monongahela people have been particularly helpful in designating several hundred acres for research—in addition to the Fernow Forest.

Perhaps our most consistent cooperator has been the Division of Forestry of West Virginia University. E. H. Tryon, of the staff there, has worked cooperatively with us for more than 20 years. Other departments of the University and many individual professors have cooperated in research with the Laboratory staff. Several graduate students have written theses based on work done on the Fernow Forest.

It is impossible to mention all the agencies and individuals who have enhanced the research program through their cooperation. Following are some of the many: Soil Conservation Service, other research units of the Northeastern Station, Allegheny National Forest, Jefferson National Forest, State and Private Forestry, Maryland Department of Forests and Parks, Shippensburg State College, Virginia Polytechnic Institute, Pennsylvania State University, Glenville College, Davis and Elkins College, AGRICO, Kaiser Chemical Company, WESTVACO, Union Carbide-Olefins Company, Ohio State University, Muskingum Conservancy District, New York State University College of Forestry, and University of Georgia.

Multiproject Program

In 1970, Warren Doolittle, at that time director of the Northeastern Forest Experiment Station, appointed a four-man committee to: (1) explore the feasibility of developing an interproject or multiproject program of research; (2) to propose areas of potential cooperation; and (3) to suggest an organizational structure to get the job done. The committee was composed of the following project leaders: Donald Cuppett (Forest Products Marketing Laboratory at Princeton, W. Va.), James Patric (Parsons Timber and Watershed Laboratory), John Gill (Forestry Sciences Laboratory at Morgantown, W. Va.), and G.R. Trimble, Jr. (Parsons Timber and Watershed Laboratory). Within 6 months, a report was prepared, submitted, and approved—with a few minor changes made by the Upper Darby and Washington offices.

Two reasons triggered the proposal of a multiproject program: (1) the greatly expanded interest in use of forest land by a large number of people who are oriented to different uses; and (2) the need to present research results in a more complete form so that they would be more easily usable by practitioners.

The following problem areas were approved for cooperative research:

1. Assemble and evaluate existing knowledge about resource management and synthesize it into recommendations and an array of options for multiresource management.
2. Determine the ecological consequences of alternative timber-management systems.
3. Develop methods of displaying and comparing alternatives for use in allocating forest-resource capabilities.
4. Develop more economical logging systems with emphasis on thinning in pole-size stands and on esthetic considerations in all situations.
5. Evaluate, from physical-site and recreation-user standpoints, administrative and management alternatives that can be used to restore overused recreation sites.

It was decided to make no changes in the structure of the projects to accomplish the additional research entailed in this new activity. Instead, because each problem would call for a somewhat different mix of talents, different people would be needed to work on each problem. The multiproject problems would be solved, not by shifting people around, but by assigning duties to people in existing projects. This meant some changes in work loads, and the new activities had to be planned for.

The work called for in problem 1 was completed in 1974 with the publication of a paper describing some options for managing forest land in central Appalachia. The final report covering the work called for in problem 3 is almost complete. Work on problem 4 has been under way on the Fernow Forest for about 2 years. This work, to date, has included the testing of two different types of logging equipment: Chuball, or ball skidding; and overhead cable skidding with the URUS skyline equipment. The Chuball proved to be impracticable, but the URUS definitely has possibilities. The success of the equipment-testing research rests in considerable measure on the ingenuity and mechanical ability of Paul Smithson, current logging boss.

The URUS cable skyline system, developed in Europe for logging steep mountainous terrain, is being tested on the Fernow Forest.

Foreign Forester Training Program

A number of foreign foresters have visited the Parsons Timber and Watershed Laboratory. For a 10-year period, during the mid and late 1950s and the early 1960s, this was considered to be the foremost location in the United States where foreign foresters were sent for training in mountain hardwood forestry. Primarily, they came to study logging methods and watershed management.

We have hosted a total of more than 500 foreign visitors. Among them were student foresters and chiefs of national forestry agencies; included also were university professors, private foresters, and foresters working for the United Nations. The length of their stays ranged from a couple of hours to 6 months; and they came from more than 35 countries.

Dissemination of Research Results

The results of our research are disseminated by word of mouth, through publications, and by demonstrations on the ground—what we call show-me trips. In addition to the many informal discussions, Laboratory personnel present 5 to 10 formal papers a year at meetings of various groups. From the unit's inception in 1948 until 1976, Laboratory people have authored or coauthored 259 published papers. Ten of these were of a general nature; 108 were watershed papers; and 141 were on timber-management subjects.

Discussion and publication undoubtedly result in widespread application of research results; but for many users, demonstration on the ground is the real clincher that determines whether or not the information will be applied. For this reason, we have stressed the development of meaningful show-me trips. Because many of our studies are carried out on large areas and are long-range in nature, our type of program is ideal for the practical demonstration of research results. About 500 information seekers participate annually in these trips.

The Zero Trail on the Fernow Forest—originally an access trail—runs 7 miles through steep country on a zero grade.

The timber-management research staff in 1976. Left to right: H. Clay Smith, Kathleen P. Hammack, George W. Wendel, Robert L. Rosier, and Neil I. Lamson.

The watershed management research staff in 1976. Front row, left to right: Burley D. Fridley, James H. Patric, James D. Phillips. Rear row, left to right: James N. Kochenderfer, Charles A. Troendle, Anne C. Denison, John Campbell. Gerald M. Aubertin was not present when photograph was taken.

The research support services staff in 1976. Left to right: Kenneth L. White, Dovie M. Fansler, Eddie S. Canterbury, Delbert Little.

The Fernow Forest logging crew in 1976. Left to right: Paul M. Smithson, Lee Long, Norman A. Long, Ronald C. Miller.

Roster of Regular Personnel

[TMR = timber-management research
WMR = watershed-management research]

Name	*Dates*	*Position*
Sidney Weitzman	1948 – 1956	Center leader
Thomas G. Clark	1948 – 1950	Research forester, TMR
Carl J. Holcomb	1948 – 1955	Project leader, TMR
Carl R. Barr	1948 – 1962	Logging superintendent
Geraldine Trickett	1948 – 1951	Clerk-typist
Daniel Hardy	1949 – 1963	Tree faller-choker setter
Norman Long	1949 – —	Tree faller-choker setter
Roy Hardy	1949 – 1954	Tree faller-choker setter
Burley Fridley	1950 – —	Forestry technician, WMR
George R. Trimble, Jr.	1950 – 1954	Project leader WMR
	1957 – 1973	Center leader; project leader, TMR; chief of laboratory
Kathleen P. Hammack	1951 – —	Clerk-stenographer; statistical assistant, TMR
Ronald C. Miller	1951 – —	Tree faller-choker setter
Letus Sherman	1951 – 1961	Tree faller-choker setter
Eli Fenchak	1952 – 1955	Forestry technician, TMR
Robert Lindahl	1952 – 1956	Research forester, TMR
Russell Hutnik	1954 – 1957	Project leader, TMR
Kenneth G. Reinhart	1955 – 1967	Project leader, WMR
James D. Phillips	1955 – 1958	Tree faller–choker setter
	1965 – —	Forestry technician, WMR
Wilfred Mitchell	1956 – 1961	Research forester, TMR
George E. Hart	1956 – 1961	Research forester, TMR & WMR
John Phillips	1956 – 1960	Research forester, WMR
Harry Yawney	1957 – 1962	Research forester, TMR
ohn Staley	1958 – 1962	Forest pathologist, TMR
Arthur Eschner	1958 – 1961	Research forester, WMR
Frank Roberts	1958 – 1961	Forestry aide
Carter Gibbs	1960 – 1964	Research forester; Project leader, TMR
Kathleen Polino	1960 – 1962	Clerk-typist
Gary Corcoran	1960 – 1967	Forestry technician, TMR
Robert Brisbin	1961 – 1961	Research forester, TMR
Diana Simmons	1962 – 1964	Clerk-typist
aul Smithson	1962 – —	Logging superintendent
eorge W. Wendel	1962 – —	Research forester, TMR
ohn Campbell	1962 – 1965	Tree faller-choker setter
	1965 – —	Forestry technician, WMR
ames Hornbeck	1962 – 1967	Research forester, WMR
. Clay Smith	1962 – 1967	Research forester, TMR
	1973 – —	Project leader, TMR
ovie M. Fansler	1964 – —	Clerk-typist; administrative clerk
andra Barr	1964 – 1968	Clerk typist; statistical clerk, WMR
elbert Little	1965 – —	Maintenance worker

Benjamin O. Backus	1965 – 1967	Administrative assistant
Allen Hopkins	1965 – 1966	Forestry aide, WMR
Lee Long	1966 – —	Tree faller-choker setter
Charles Troendle	1966 – —	Research forester, WMR
Luther Auchmoody	1966 – 1971	Research forester, TMR
Robert Rosier	1967 – —	Forestry technician, TMR
Merle Grant	1967 – 1969	Administrative assistant
James Patric	1967 – —	Project leader, WMR; chief of laboratory
James Kochenderfer	1967 – —	Research forester, WMR
Anne Denison	1969 – —	Clerk-typist, statistical assistant, WMR
Eddie S. Canterbury	1969 – —	Administrative assistant; business-management specialist
Gerald M. Aubertin	1970 – 1976	Research soil scientist, WMR
Cecil A. Yockey	1970 – 1972	Forestry technician, WMR
Kenneth White	1973 – —	Maintenance worker
Neil I. Lamson	1974 – —	Research forester, TMR

SOME OF THE PEOPLE

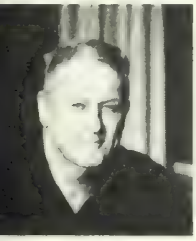
who have served on the Fernow Experimental Forest and at the Parsons Timber and Watershed Laboratory.

dney Weitzman

Thomas G. Clark

Carl J. Holcomb

Carl R. Barr


rge R. Trimble, Jr.

Robert R. Lindahl

Russell J. Hutnik

Kenneth G. Reinhart

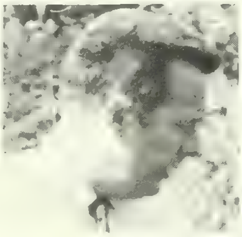
lfred C. Mitchell

George E. Hart

John J. Phillips

Harry W. Yawney

Arthur R. Eschner


Carter B. Gibbs

James W. Hornbeck

Benjamin O. Backus

Luther R. Auchmoody

Merle B. Grant

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Trimble, George R., Jr.
1977. **A history of the Fernow Experimental Forest and the Parsons Timber and Watershed Laboratory.** Northeast. For. Exp. Stn., Upper Darby, Pa.
46 p., illus. (USDA for. Serv. Gen. Tech. Rep. NE-28)

U.S. Forest Service timber-management research in West Virginia began in May 1934 when the Fernow Experimental Forest was established. Except for the war years in the 1940s, an ever-intensifying program of research has been carried out in both timber and watershed management. Lists of publications and personnel are appended.

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Headquarters of the Northeastern Forest Experiment Station are in Upper Darby, Pa. Field laboratories and research units are maintained at:

- Amherst, Massachusetts, in cooperation with the University of Massachusetts.
- Beltsville, Maryland.
- Berea, Kentucky, in cooperation with Berea College.
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Proceedings of the SYMPOSIUM ON INTENSIVE CULTURE OF NORTHERN FOREST TYPES

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USDA FOREST SERVICE GENERAL TECHNICAL REPORT NE-29
1977

FOREST SERVICE, U.S. DEPARTMENT OF AGRICULTURE
NORTHEASTERN FOREST EXPERIMENT STATION
6816 MARKET STREET, UPPER DARBY, PA. 19082

FOREWORD

THE NORTHERN FOREST TYPES constitute a vast natural resource for the United States and Canada. For instance, in the eastern United States there are more than 10 million acres of commercial forest land supporting spruce and fir types alone. The magnitude and variety of this resource is such that treating it in any detail at a 3-day meeting was impossible. Rather, the idea that germinated and developed into this symposium was to present a broad picture of the extent of our knowledge of intensive cultural techniques, the status and trends of our research in the northern forest types, and some actual experiences in managing this resource; and to explore those factors that affect our use of the intensive cultural techniques we have at hand.

There is no doubt that we face a new era in the management of northern forests. The production of wood products is no longer the primary objective of many owners, and increased pressure for the social values of our forests is being felt by all landowners. We must recognize these other forest values, which in turn dictates intensification of all aspects of forest management if we are to meet the future demands of a wood-hungry society.

The enthusiastic efforts of the symposium sponsors—the School of Forest Resources, University of Maine; the Maine Bureau of Forestry; the Maine Forest Products Council; and the U.S.D.A. Forest Service—and the individuals behind those efforts, should be commended. Special thanks are due to Great Northern Nekoosa, Inc., and Brooks B. Mills for their help in providing interesting field trips, and to the Casco Bank and Trust Co. for sponsoring the symposium brochure. Also, without the enthusiastic participation of the experts invited to present papers, and the moderators of each session, the Symposium could not have taken place.

—BARTON M. BLUM
Symposium Chairman

PUBLISHER'S NOTE

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Proceedings of the SYMPOSIUM ON INTENSIVE CULTURE OF NORTHERN FOREST TYPES

held 20-22 July 1976 at Nutting Hall, University of Maine, at Orono.

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Ed Giddings, University of Maine, Orono.
Robert Frank, USDA Forest Service, Orono, Maine.
Ken Hendren, Maine Bureau of Forestry, Augusta.
Jack Bulger, Maine Bureau of Forestry, Ellsworth.
Bill Adams, Maine Bureau of Forestry, Old Town.
Jonathan Ford, J. M. Huber Corp., Old Town, Maine.

Moderators

Fred Knight, School of Forest Resources University of Maine: 20 July 1976, morning session.

Fred Holt, Maine Bureau of Forestry (retired): 20 July 1976, afternoon session.

Ray McDonald, Casco Bank & Trust Company: 21 July 1976, morning session.

Dick Kennell, USDA Forest Service, State & Private Forestry: 21 July 1976, afternoon session.

C. D. Hartley, Valley Forest Products Ltd., Canada: 22 July 1976, morning session.

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DISCUSSION PAPERS

Below is a list of discussion papers on important topics that were presented Tuesday evening, 20 July. These papers are not included in the proceedings, but copies may be obtained from the authors.

"Summer planting of container-grown northern hardwoods": Raymond E. Graber, plant ecologist, USDA Forest Service, Durham, N.H.

"Planting and intensive culture of yellow birch to improve timber quality and production": Peter R. Hannah, associate professor of forestry, University of Vermont, Burlington.

"Birch management—cleaning and weeding": R. W. Nash, G. A. LaBonte, and F. H. Manning, Department of Conservation, Augusta, Maine.

"Spruce-fir silviculture and management in the northeast": Robert M. Frank and Ken Lancaster, USDA Forest Service, Orono, Maine (slide-tape program).

"Opportunities and limitations of northern forest types in Alaska": John Galea, Alaska Planning Team, Anchorage, Alaska, and John Zasada, Institute of Northern Forestry, Fairbanks, Alaska.

"Economic aspects of intensive management; directions of technological change currently inappropriate": Lloyd Irland, Department of Conservation, State Bureau of Forestry, Augusta, Maine.

TRANSLATING FORESTRY KNOWLEDGE INTO FORESTRY ACTION

by John R. McGuire, Chief, Forest Service, U.S. Department of Agriculture, Washington, D.C.

Abstract

The non-Federal forest lands, which comprise three-fourths of the Nation's forest lands, are the key to meeting projected future needs for all forest products and uses. At the same time, the Federal role in State and Private forestry cooperative programs is being critically questioned. Public attitudes toward Federal expenditures, and the possibility of sunset legislation, may change the nature of Forest Service cooperative programs. One possible approach would be for each State to develop a comprehensive forestry plan suited to both State and national needs, perhaps related to a national program expressed through the Resources Planning Act process, as a basis for granting Federal funds for cooperative forestry activities.

I am very pleased to have the honor of opening this symposium. It's good to be back once again in the great State of Maine and to be a part of what promises to be a very productive and interesting discussion of the culture of northern forests. We all know that here in Maine, the State that proudly claims the highest percentage of forested land in the Nation, the future economic outlook depends upon intensive culture of all lands. And, in Maine, this means private forest lands. Certainly, no State depends more on its forest lands.

The agenda for this conference promises a rather comprehensive review of the culture of northern forest types. But, to get the meeting underway this morning, I'd like to set the background in a way quite different than you might expect.

I have been increasingly concerned in recent months about the outlook for State and Private forestry in this Nation. Unprecedented challenges face us in the next few months and years regarding the non-Federal forest resource.

There are many reasons for each of us here today to be concerned about State and Private Forestry. After all, the silvicultural knowledge that has been so painfully acquired over these many years finds much of its application on the three-fourths of the Nation's forests that are privately-owned.

In addition, the Assessment of forest and rangeland resources prepared under the Resources Planning Act confirmed that small, non-industrial private forestlands are the key to meeting increased needs for wood and other forest products in the next half century.

But, how do we get this land into production? There seem to be almost as many theories on this as there are speeches during an election year.

The challenges that face State and Private Forestry today are substantial and real. For example, when the President transmitted the Resources Planning Act documents to the Congress early this year, his Statement of Policy stressed concerns over the Federal role in State and Private Forestry. Today there is unprecedented questioning of the effectiveness of, and the rationale for Federal participation in programs targeted toward non-Federal lands. There is a strong feeling that the private sector and the States can and should provide the investments in and management of these lands. There is a strong feeling that the market forces are adequate to assure sustained and adequate supplies of timber and other forest resources far into the future. Thus, the Federal role in S&PF cooperative programs is being critically questioned.

Another dimension of this new concern is the so-called Monongahela controversy. Certainly any legislation which changes the 1897 Organic Act could have far-reaching implications for private forestry. If timber flows from the National Forest System are reduced through legislative direction, and assuming that demand for timber products continues as projected, it is obvious that the vast acreage of non-industrial private land in particular will feel the brunt of increased pressure for harvest.

Let me assure you that the Forest Service considers the State and Private function a major responsibility. It is an essential part of the total mission of our agency. We are well aware that the greatest remaining challenges to forestry in this Nation are found on these lands. We know that the interrelationships between State and Private Forestry and the National Forest System--particularly in the West--and with Research, are strong, and mutually supportive. We know that in many States--and Maine is a good example--private forest lands form a large part of the foundation of the economic and social well-being of the people. We intend to do our best to meet the emerging challenges of S&PF.

For those of you who may want to do some reading on this general subject, there are many recent analyses--for example the latest Forest Service "Timber Outlook Report" is a reasonably fresh set of statistics on forest land capability. The Resources Planning Act Assessment released in January is another. The President's Advisory Panel on Timber and the Environment put out a very comprehensive report in 1973. The National Commission on Materials Policy Report of the same year also paints a strong picture of the major significance of private forests in the United States.

We know what the challenge is. Now, how do we meet it? First, I would note that there is now, and has long been, a widespread philosophical opposition to subsidy or incentive payments to private landowners. Yet, it seems apparent--and here's where we need more analysis and data--that the typical non-industrial landowner simply will not make the investments needed in reforestation and intensive culture without some external motivation. All of us are aware of the reasons for this. But, what is lacking is a definitive analysis and projection of what would take place in the private sector without Federal or State intervention.

Some economists claim that the market place is the best arbitrator of national demands and supplies. Yet recent history has shown that market forces are not adequate to get small, non-industrial holdings into production. There has been little response to the sharp stumpage increases a few years ago and most landowners are fully aware of the fluctuations in the market price for timber--and the reality that most harvesting on their land will be done by the next generation.

I am sure this audience is well aware of what I might call the inadequate technology transfer of forestry research. We simply are not getting enough of our research findings applied on the ground. There are still many barriers that lie between the advancements of the research scientist and the practicing forest manager. Much of that linkage must come from State and Private Forestry activities such as the Cooperative Forest Management Program and from Forestry Extension programs.

There is also clearly an inadequate data base for benefit-cost determination, program evaluation, accomplishment reporting and other quantitative expressions of the effectiveness of Cooperative Forestry Programs. Until we overcome these inadequancies, we are of necessity put in the position of arguing for technical and financial assistance to State and private landowners without the necessary facts in hand.

I could elaborate for some time on the challenges facing us in State and Private Forestry as we begin this third century, but instead I would prefer to discuss some of the possible ways in which we, as a Nation, can assure that these lands are managed and protected.

Let's first take the definition or rationale for the Federal role in S&PF. Many would argue that the Federal role is and should be a catalytic role. For example, the Clarke-McNary law of 1924 established the Cooperative Fire Protection activities commonly known as CM-2. After some 52 years, the President's Office of Management and Budget argues that the program has been successful as a catalyst and should be terminated. The States have been able to establish strong capability in forest fire protection and therefore, the argument goes, there is no need to continue an outlay of some $20 million a year in payments to States. They point out that the Federal share now amounts to only about 15 percent of the total expenditures. On the other hand, the State Foresters and Congress argue that there is a continuing Federal responsibility to share the cost of protecting the Nation's private forest lands. Put simply, they conclude that it is in the national interest to have well-protected forests. The President proposes no further payments to States for this activity. The Congress, however, continues to appropriate the funds.

Another illustration, of great significance here in Maine, is the Cooperative Forest Pest Control project. As you well know, the Spruce Budworm outbreak here and in Canada is causing great and continuing concern. In recent years, the Federal Government, through the Forest Service, has contributed many millions of dollars in repeated attempts to reduce the losses from Spruce Budworm. The State has just completed the largest aerial spraying in forestry in the United States, some 3 1/2 million acres. There are those who argue forcefully that the Federal role in pest control should be much less than a 50-50 partnership, in terms of dollars expended.

And so we are faced with the continuing need to analyze and rationalize, and establish a consensus on, exactly what the Federal role should be in protecting, developing and managing private forest lands.

Developing a rationale for Federal participation in Cooperative Forestry Programs is not something that lends itself to scientific analysis or linear programming or any other kind of hard data manipulation. Rather it is in the more difficult area of policy over what might be termed "shared responsibility" among interested parties.

To approach this question we plan to have a series of discussions with the parties concerned. For example, here in Maine later this year we plan to meet with all of the interests involved and review our strategy on Spruce Budworm control. We hope to have our Canadian friends participate in that program. This will not be a large conference, but rather a small group of the decision shapers and makers who must determine what each of the various roles should be in facing a very serious threat to Maine's forest resources. Out of that discussion, we hope to identify what the Forest Service role should be, as well as the roles of the State, private industry, and small landowners.

Another dimension of the emerging challenge to S&PF is finding much better ways of targeting the Federal contribution to Cooperative Forestry Programs. Most of the payments to States are based upon a formula distribution that attempts to provide equity among the States in receiving their share of the Federal funds made available for fire protection and technical assistance to landowners through the Cooperative Forest Management Program. In both of these long-standing programs, the formula distribution procedure is increasingly questioned. As the States increase their capability, and become dominant in the sense of far-overmatching the Federal dollars, there is less and less weight to arguments for providing Federal dollars to stimulate the program. Instead, what is needed is a targeted or directed use of Federal dollars for specific purposes, with accountability that will make possible cost-effective analysis of the Federal participation.

We are beginning to move in that direction as we work with our cooperating State Forestry agencies in revising our approaches to meet the new situation. The situation, obviously, is far different in 1976 than it was in 1924 or 1950, when these major pieces of legislation were enacted.

One illustration of the targeting approach is our so-called Sawmill Improvement Program. This activity comes under the Cooperative Forest Management Act funding and is targeted to aid mills who request assistance in improving their operations. The State Foresters and the Forest Service have been quite successful in providing this kind of technical assistance--and the results have been quite dramatic. The output of lumber from the same volume of logs going to the mill has been increased an average of about 13 percent simply by following better quality control procedures. The potential is there for even greater increases in yield. This is a good example of the effectiveness of applying some of the research knowledge that is developed at the Forest Products Laboratry and elsewhere.

The public's attitude toward Federal government expenditures is also a major element in the future role of State and Private programs. Some critics claim that we have too much government, too much bureaucracy, too many programs that are initiated but never terminated. The Office of Management and Budget has taken the stand that Federal agencies will not continue to do "business as usual." Sunset legislation may become the law. In fact, Congress and the States share this feeling to a large extent. In other words, I do not foresee that a law passed in 1976 can continue on for decades, as have the Clarke-McNary law of 1924, the Forest Pest Control Act of 1947, the CFM Act of 1950, and other major pieces of Cooperative Forestry legislation. Rather, we should think in terms of completion dates for programs, whether they are 5 years or 10 years or whatever. We should set a target to accomplish a specific objective and then conclude the program and move on to something else. The Rural Community Fire Protection Program is one illustration of Congressional direction in this regard. It provided for a 3-year pilot program and there is every indication that if the legislation is renewed it will have a very precise time limitation.

Closely tied to all of this is the need for better program evaluation. Federal legislation is increasingly requiring formal program evaluation. Both the Forestry Incentives legislation of 1973 and the Rural Community Fire Protection legislation of 1972, for instance, have this requirement. The picture emerging clearly shows increased attention to the effectiveness of various State and Federal programs. Agencies such as the Forest Service must justify and prove the effectiveness of their activities more than ever before. And this means that we must develop an adequate basis—a factual basis--for program evaluation that is much better than we have ever had before.

There is no doubt that private lands--particularly small, non-industrial holdings—are the key to meeting the future demands for forest resources. And please remember that while this conference deals mainly with wood supplies, the demands for other forest uses are increasing just as rapidly--in some cases, more rapidly.

Those of you in the Northeast are well aware of the escalating demand for recreation, for both developed facilities and wilderness opportunities. The Allagash River is a classic example of what can happen when user demand outstrips the available resource--and the resource suffers. In other areas of the country, use of Federal rangelands is becoming highly controversial--and decisions have to be made that balance the Nation's red meat needs with the need to protect the rangeland resources. All other resources from our forestlands--water, wildlife and subsurface minerals—are also priority candidates for intensive management.

Incentives, education, and other forms of assistance are one approach to insuring adequate management and protection of private lands. But there is another approach which has become more dominant in the last few years--and this is regulation. On the Federal level, we have such laws as the Federal Water Pollution Control Act Amendments of 1972. At the same time, many States are rushing to enact their own requirements, involving everything from forest practices acts to coastal zone management. Federal and State legislation is surfacing many debates--what lands should be regulated, what level of government should do the regulating, and just as importantly, who should foot the bill?

Nor can we dismiss the international picture when we talk about meeting future needs in this country. Last year marked the first time in history that the dollar value of our timber product imports caught up with our exports.

I think these considerations--coupled with requirements for 5-year reporting periods of Forest Service accomplishments under the Resources Planning Act--logically point to some new future directions in our Cooperative Forestry programs. Let me conclude by expressing a hope about where we may find ourselves moving as we progress through the remainder of the 1970s. Basically, we are placing our hope in the idea that in each of the 50 States it will be possible to develop a comprehensive forestry plan.

One way in which this might work is through a block grant approach, very similar to the Federal revenue sharing program. It could perhaps be a 10-year plan, starting with a State resource assessment, tying into national needs as expressed through the Resources Planning Act process, and progressing to each State organization developing a forestry plan suited both to that State and to national needs. The Forest Service would then evaluate the plan, and provide a block grant to implement the plan.

Last March I wrote to each of the State Foresters, in effect challenging them to pick up this "mantle of leadership," through their resources planning process and to provide much of the State leadership necessary to bring together the various interests in forestry assessment and program development. I am happy to tell you that almost every State Forester responded positively. They are ready and willing to move forward in this direction.

I hope these comments have helped set at least a part of the stage for this symposium. I'm sure you will touch on many aspects of the need for technology transfer and for applying forestry knowledge to non-Federal lands. I believe that all forestry interests--scientists as well as practitioners--must focus their attention on this vast acreage of productive forest land that is one of the rich blessings of this Nation. It is simply not enough to know how to achieve intensive culture of northern forest types--or of any other forest type. We also need to be able to deliver that know-how and to make it effective. Transforming knowledge into action will require the coordinated efforts of all of us who are dedicated to the management and protection of this Nation's forest resources.

WOOD AS A STRATEGIC MATERIAL

by Kenneth S. Rolston, Jr., executive vice president, American Pulpwood Association, Washington, D.C.

Over the medium and long run timber can provide a major contribution to improving the balance of payments caused by the increase in oil prices. It can do so without causing severe shortages at home. This is basically the position held by most senior executives in the forest industry and I'll try to discuss briefly some of the factors necessary to fulfillment of their prognosis.

First, however, let's look at the other side.

> Let's not export our logs until we know we have enough timber for our own uses. Let's not back ourselves against the wall. Let's cut off exports and provide for our home industry. We can change later is we see we have an adequate supply.

This is a warning from a "Friends of the Earth" spokesman calling for an export ban on logs from National Forests.

In further support of the shortage advocates, Bruce Zobel of North Carolina State University in an article in American Paper Industry magazine predicted shortages of quality pine and hardwood in the South.

If our forests are to become strategic in the sense that sufficient excess production will be available for export, policy corrections will have to be made and these must be based on careful analysis of a number of controlling factors. The first is the worldwide market situation and prospects.

In recent years there has been a rapid increase in the worldwide use of wood. Population growth is one factor but other important influences are improvement in the standard of living, technological changes resulting in new products, acceptance of more species as industrial raw material, and use of wood for fuel as oil prices increase. Demand in Europe and Japan is expected to show fast growth. Projections indicate European demands will double by 2000, primarily for pulp and paper products. Limited European timber supplies are expected to result in major annual deficits as high as seven billion cubic feet. Japan is already dependent on imports for over half of its requirements and this deficit situation is predicted to increase for at least several decades until her forests may be able to improve their yields.

We're familiar with predictions of U.S. demand in the year 2000; double for paper and board and substantial for lumber and plywood. In that year we'll have 55 million more people and expect a much higher standard of living.

The FAO predicts world demand to rise by 45 billion cubic feet in the 1975 to 1990 period, nearly 50 percent. Fuelwood is expected to account for 20 billion cubic feet and pulpwood for 15 billion cubic feet in that period leaving an increase of 10 billion cubic feet for sawlogs and panel products.

If we accept the premise that the markets will be there, where will the wood come from?

A recent study for the American Pulpwood Association made by Jaako Poyry, a worldwide forestry consulting firm, looked at the worldwide supply of wood along with present and future demand to the year 2000.

The firm identified Japan, Europe, the United States, China, and India as areas that will need more wood than they can supply. On the other hand, Canada, Siberia, Brazil, tropical Africa, Indonesia, and Burma are expected to have surpluses. These regions will have problems and drawbacks that will prevent actual utilization of their wood.

Brazil is planning rapid expansion of her forest industries including expanding pulp production from one million tons in 1972 to six million tons in 1985. Brazil is expected to use most of the increase in production so the amount available for export to the deficit countries will be of marginal importance. Lack of a developed economy, lack of technical know how and other problems will continue to impede development and use of Brazilian forest for years to come.

The same problems exist in tropical Africa to an even greater degree and Asian wood is likely to be utilized primarily in that region.

Although the Soviet Union has surplus growth, most of the wood for its expansion will have to come from Siberia - an area lacking infrastructure located a tremendous distance from the final market. It is expected that Soviet domestic consumption of wood products will keep pace with the rate of production. For example, their consumption of paper per capita is only 1/10 that of the United States.

Canada has vast unutilized forest reserves and the potential for nearly doubling its allowable cut but much of its forests are economically inaccessible. Increasing distances from woods to mill as nearby forests are cut, the problem of getting sufficient labor to the woods and rapidly increasing costs will probably prevent large expansion of the Canadian industry.

It is hard to imagine the U.S. as a "deficit" area. Our supply of wood has always been more than adequate and we have had a surplus of growth over drain for many years. The rise in exports since 1950 has just about offset the increase in imports and there hasn't been much change in net trade. Net imports in 1973 were 1.6 billion cubic feet, some 12 percent of total U.S. consumption.

The prognosis reached by Jaakko Poyry is of most interest:

> The final conclusion is that, in spite of vast unutilized forest resources in differ-

> ent parts of the world, it will be difficult to supply the deficit areas of the world with wood from surplus areas. Thus, the deficit regions must contribute much more than is usually assumed. Those regions generally have a well-developed infrastructure and an established industry close to the market. Therefore, the forest industry within these regions should be capable to pay a quite high wood price before it is more economical to invest in countries with less developed economy. Higher wood price means that more money can be invested in silviculture and other measures to increase forest production. The most interesting region in this regard is, without doubt, the USA, which has a potential for an increased harvest both for softwood and hardwood. The potential is big enough not only to supply the expected deficit but also to turn the US to a net exporter of forest based products.

So the real question is how to get from here to there. How can the U.S., in a few decades progress from deficit status to surplus? You will get the answers over the next several days and then be ready to go out and put them into practice in the field.

In simplified fashion the answers given to the question, at least in my mind, fall into two categories:

1. Increase productivity on all classes of forest lands
2. Improve utilization of the timber we harvest

The list of tools in our forestry toolkits aimed at increasing productivity is long and will be explored in depth during your symposium. Whether they will be used to the extent necessary to make wood a strategic material depends on policy decisions and resultant capital availability. Policy decisions with respect to public and private forests may in the future provide the motivation for allocation of capital for forest productivity, or may move even more to withdrawals from the forest land base for other uses and non-economic restrictions on forest productivity to achieve social or environmental goals. The forestry profession has a part to play in the decision making process but in the final analysis I am not optimistic about the current chances for using economics or world trade opportunities as "hot buttons" for our legislators. We have a lot of work to do.

We have shown our ingenuity in increasing utilization of mill and forest residues and we can and will do more. Seminars and symposiums on the subject abound and there's no need for me to try to go into detail. Those of us with industry are proud to point out that with only 13% of the forest land we supply one third of the harvest. But we have not been able to develop or implement ways to similarly increase output from public and nonindustrial private ownerships.

This symposium does show that we're aware of our potential and want to get on with the job ahead. Wood can be a strategic material and forestry technique can increase productivity and improve utilization. Can we influence policy decisions so that capital will be allocated to do the job?

In closing I'd like to talk about the current situation in Sweden as an example of how a deficit situation can occur and the steps that country has taken to try to bring supply back into balance.

In 1974 Sweden was still a net exporter of unprocessed wood. Norway received 600,000 cords of roundwood and 160,000 cord equivalents of chips. The net export to Finland was 50,000 cords of roundwood. Small quantities were imported from Germany, Poland, the Soviet Union and the United Kingdom.

In 1975 the picture in Sweden changed and Sweden's forest products industry faced a shortage. Harvest was estimated to be 12% higher than growth. The report of the Swedish State Commission on National Forest Resources indicated that if the gross cut were maintained until 1980, at a level corresponding to the industry's 1973 consumption, the harvest from Sweden's forests would thereafter have to be reduced by 20% to achieve a sustained long-term yield.

Swedish forests are among the most intensively managed in the world. Why did Sweden get into this situation? There are some reasons:

1. Up until 1973 wood prices had remained about the same for 15 years while costs had increased. As a result, the economics of Swedish forestry suffered a consistent downward trend. Inadequate reforestation resulted and timberstand improvement activities were curtailed due both to lack of funding and environmental restrictions on chemical spraying.

2. Another critical concern for Swedish forestry is an unfavorable distribution of forests by age class. Sweden has a relative shortage of forests aged 20-40 years as the result of extensive thinning operations which did not create enough young forests and slow start-up of new stands due to insect damage and overcrowding.

3. Statistical surveys on the condition of Swedish forests were overly-optimistic. The "margin of error" is unclear.

The Swedish government took action. Restrictions were made on industry expansion unless it was based on imported raw material. Investments in intensive management of state-owned lands were escalated and a new more detailed forest survey was begun.

Swedish companies began to look for a new source of wood. After looking at all possibilities throughout the world they determined that the United States would be the best source of supply from both an economic and political standpoint.

Since then, Wood Fiber Market Corporation has been formed in the United States by sawmill owners to sell chips to Sweden. Louisiana Pacific Corporation is constructing chip export facilities at Lake Charles, LA, Weyerhaeuser has exported eight shiploads from Morehead City, NC and Georgia-Pacific is planning a deep water export facility at the Port of Savannah, GA.

There are some lessons for us in the Swedish experience. We must not wait until the limits of our forest resource are hard upon us. We must provide reasoned and effective opposition to those who would further restrict forest productivity. This nation has the potential for world leadership in forestry. We have the means and must find the ways to stimulate action.

NATIONAL AND REGIONAL NEEDS FOR INCREASING WOOD YIELDS THROUGH INTENSIVE MANAGEMENT

by Robert B. Phelps, research forester, Forest Economics and Marketing Research Staff, USDA Forest Service, Washington, D. C.

Abstract

Several recent studies show that U. S. timber markets are likely to grow rapidly in the next few decades. Part of the rising demand can be met by increasing the utilization of the timber harvested and more efficient manufacturing and construction processes. In addition, part of the increase can probably be supplied by rises in net imports, particularly at higher price levels. However, it seems clear that to meet prospective increases in demand much beyond the 1970's, it will be necessary to grow more timber in domestic forests. There are opportunities for increasing supplies from all ownerships and in all sections of the country. Through intensified management, domestic forests have the capability of producing at least twice the volume of timber they are growing today.

In recent years, spectacular increases in the price of stumpage and timber products, difficulties of many mills in obtaining wood, and concern about the future adequacy of our timber supplies has created a lot of interest in our prospective timber situation. This has resulted in a number of congressional hearings and studies. Since 1968, there have been at least 12 major studies and reports on the topic.

"The Outlook for Timber in the United States", prepared by the Forest Service (which will form the basis of most of my talk), the "Report of the President's Advisory Panel on Timber and the Environment", and "Timber: The Renewable Material", prepared for the National Commission on Materials Policy, have been widely distributed and are probably familiar to many of you. Some of you have also seen and possibly reviewed a draft of the Forest Service's assessment of all renewable resources which was required by the Forest and Rangeland Renewable Resources Planning Act of 1974.

Although there are substantive differences among the reports in content and objectives, the major conclusions about the timber outlook are in remarkably close agreement. For example, there was agreement that the Nation's demands for timber products are likely to grow rapidly in the decades ahead. Since this is an important conclusion in analyzing our timber situation, I would like to briefly discuss its basis. I will follow this with a discussion of the possible ways of meeting the projected increases in demand.

Patterns of past consumption provide one indication of future demand. A look at recent trends shows that U. S. consumption of industrial roundwood (i.e., all timber products except fuelwood) increased from 9.9 billion cubic feet in 1950 to a peak of 13.4 billion in 1973--a rise of some 35 percent. Consumption fell in 1974 and again in 1975 as economic activity in most of the major markets declined. Particularly important were the down-swing in housing output, which in 1975 dropped to the lowest level in about 30 years, and the declines in paper and board demand. In response to these trends, consumption of industrial roundwood dropped to 10.7 billion cubic feet in 1975--about a fifth under 1973 demand. Despite the sharp decline, however, 10.7 billion cubic feet is still 5 percent above average consumption in the early 1960's. Current trends indicate that total consumption for 1976 will be somewhat larger than in 1975 and probably rise further in 1977.

Now these data on what has been happening are interesting and instructive as I noted before. However, our basic concern here is in what lies ahead. Can we expect continued growth in demand or is the current cyclical down-turn a harbinger of things to come?

Today, the future appears to be much more uncertain that it did a few years ago. The large jump in the price of fossil fuels, inflation, and the other problems that we face could materially affect economic growth and future markets for timber products. However, our historical experience suggests that we will surmount our present difficulties and that we can, with some degree of confidence, expect markets for timber to continue to expand and grow.

One of the important indicators of future demands for timber products is population. Recent trends in fertility rates indicate that population growth is likely to be below what had been generally anticipated in the 1950's and 1960's. Nonetheless, the most recent Bureau of Census projections show that if present fertility and immigration rates continue, the Nation's population will be some 265 million people in 2000, about 50 million more than we have today. I know that this is difficult to relate to timber demand. But perhaps it may help to realize that an increase of this size is about four times the current combined population of the six New England States. When you consider the number of houses, stores, schools, factories, and other structures in this area, you can begin to appreciate what the anticipated growth in population means in the way of additional demands for timber and other materials.

In addition to this increase in numbers, the income available for people to spend is likely to continue to grow rapidly. Most recent projections, for example, indicate that per capita disposable income will more than double by the year 2000. This means, of course, that we will not only be faced with the task of meeting the additional demands of 50 million people, but the demands of 265 million people with a much higher standard of living.

On the basis of these kinds of expectations about population and economic and income growth, it seems clear that we are faced with the prospect of large increases in the demands for most timber products. The demand for paper and board, for example, is projected to roughly double by the year 2000. The demand for pulpwood is expected to show a similar rise. Projected demands for lumber and plywood also show substantial increases.

There seems to be only three practical ways of meeting the projected increases in demand. First, we can improve the efficiency with which we utilize the timber we harvest; second, we can increase the volume of net imports; and third, we can grow more timber in our domestic forests.

We have made large gains in the utilization of wood material that once presented a residual disposal problem. For example, the volume of chips--products from slabs, edgings, veneer cores, and other similar coarse material--consumed in woodpulp mills increased from 1.3 million cords in 1950 to nearly 28 million cords in 1974. Use of sawdust, shavings, and other fine material for pulp and particleboard also has been increasing.

While these gains have been impressive, there is the potential for far greater increases. In 1970, for example, more than 20 million cords of wood were left unused in the forests after logging or land clearing. This was the material left from what we call growing stock (i.e., live desirable or acceptable trees of commercial species more than 5 inches in diameter at breast height). There are much larger volumes of rough and rotten trees, dead trees, limbs, material under 4 inches in diameter, and roots available for use. As you all know, we are beginning to use this material; whole tree chippers are coming into common use in some sections of the country, and developmental work is underway aimed at making it economically feasible to utilize the taproots of some species such as the southern pine.

In addition to these kinds of residues, there was approximately 12 million cords of wood left unused in primary manufacturing plants in 1970. There were also large volumes of waste paper and other secondary manufacturing and consumer residues available for use.

A substantial part of the residues I have been talking about occur in such small volumes or in locations so remote from processing facilities that they are not now, or are they likely to be, economically usable. Nonetheless, the potential is great and this resource is likely to be drawn upon to an increasing degree in the period immediately ahead.

Some of the projected increases in the demand for lumber and plywood could be met by increasing the product output from logs through the use of thinner saws and more precise manufacturing methods and equipment. Development of stress grading systems and better product design could also extend supplies by increasing the efficiency in the use of lumber and plywood in manufacturing and construction. There is also the possibility of increasing pulp yields, although in recent decades technological advances in this direction have apparently been offset by the losses associated with the increasing production of semi-bleached and bleached pulps.

When all things are added together, it seems clear that the potential from improved utilization is large. However, even the most optimistic estimate of prospective gain is far below the projected increases in total demand.

I would now like to turn to the second possibility, increasing supplies through improving our net imports situation.

Between 1950 and 1973, imports of timber products increased from about 1.5 to 3.1 billion cubic feet. Although the volumes imported dropped somewhat in 1974 and 1975, they were still above any year prior to 1966. Softwood lumber, nearly all from Canada, accounted for over half of the growth in imports in the past 25 years and pulp and paper products, also nearly all from Canada, most of the remainder. Hardwood plywood and veneer imports, chiefly made from lauan originating in the tropical forests of insular Southeast Asia, also increased rapidly, although in 1975 they still represented less than 10 percent of total imports.

The softwood timber resources in British Columbia and the northern parts of the eastern Canadian Provinces can support a much larger harvest. A substantial increase in imports of softwood lumber, newsprint, and woodpulp from this resource is thus possible, especially at the higher prices which seem to be in prospect. Tropical hardwood forests also have the potential to supply much larger quantities of hardwood plywood and lumber.

Exports of timber products, chiefly pulp products and softwood logs, have also been rising rapidly since 1950, moving up from 0.1 billion to 1.3 billion cubic feet. Exports were also down in 1975, however, the decline was not nearly as great as for imports. Most of the growth in exports has largely reflected a combination of rapid increases in demand and inadequate timber supplies in western Europe and Japan--the major importing areas--and relatively stable prices in the United States. The latest studies of the timber outlook in the importing areas indicate that demands will continue to grow and that domestic timber supplies will fall increasingly short of domestic requirements.

In summary then, it seems that if prices remain relatively stable, increasing exports will largely offset rising imports and our net import situation may not change appreciably. At higher prices, net imports could show a significant rise, especially net imports of softwood lumber, newsprint, and woodpulp from Canada.

Although part of the projected growth in demand can be met by improved utilization and increases in net imports, the potential gains are relatively small in comparison to the projected total growth in timber product markets. Thus, if the projected growth in demand is to be met, it must come from domestic resources.

As is the case with economic growth, recent developments have tended to cloud the outlook and make our domestic timber supply prospects more uncertain. Among the things I have in mind is the increasing pressure to earmark land--and particularly the public lands--for some exclusive use such as parks and wildernesses, and increasing withdrawals for residential use, highways, reservoirs, and other similar purposes.

There has also been increasing concern about the protection and maintenance of our forest environment and about the production of recreation, wildlife, water, and other nontimber goods and services of the forests. These are legitimate concerns, but they will inevitably mean added constraints on the use of forest lands for timber production.

From an analytical standpoint, many of the changes that have been taking place are in their early stages, and unfortunately it is impossible at this time to accurately appraise their ultimate impact. In projecting timber supplies, they have been recognized and an attempt has been made to take them into account.

We have been making rather substantial progress in the way we manage our forests for both timber and other products in recent decades. In the South, for example, fire control and other forestry programs, including extension work, have improved the timber situation to the point where timber harvests may be gradually increased as much as 60 percent over the next few decades. This increase will be largely offset, however, by expected declines in the harvesting of old-growth timber from forest industry lands in the West.

From the national standpoint, with present levels of forest management, future harvests of softwood timber cannot be increased above current levels without overcutting and reduced supplies of this preferred timber in some future period. Thus, if recent levels of timber management continue, we are faced with the prospect of large increases in the relative prices of softwood timber products as sharply rising demands are brought into balance with supplies.

In contrast, hardwood forests can support a much larger volume of harvests. Net annual growth on all growing stock trees 5 inches and larger, is some 3.5 billion cubic feet above removals. Most of this timber is on the small ownerships in the North, and is in relatively small trees of the less desirable species. However, it is suitable for use as pulpwood, and represents a major source of future wood supply for the pulp industry.

The prospective hardwood sawtimber situation is roughly similar to that of softwoods. Although the data on growth and removals indicate that sawtimber stands can support an increased level of cutting, recent increases in hardwood sawtimber stumpage prices suggest that the resource data probably overstates the volume of sawtimber that is economically accessible and available for sale. For example, much of the projected supply of hardwood sawtimber is in species and low-quality trees for which markets are currently limited. Much of the demand, on the other hand, is for species such as select white oak and red oak, sweetgum, yellow birch, hard maple, walnut, and black cherry, and for the larger sized high-quality trees. Removals have been close to or above annual growth for this preferred material in recent years.

In addition, part of the larger sized hardwood sawtimber that is suitable for the manufacture of high-quality lumber or veneer occurs as widely dispersed trees or groups of trees that may not be economically harvestable. A substantial part of the hardwood timber is also in privately owned tracts that are held primarily for recreation or other purposes that are not compatible with timber harvesting.

In summary, the data we have shows that if we continue to practice forestry much as we have in recent years, we will not be able to significantly increase our harvests of softwoods without overcutting. Harvests of hardwoods can be increased, although it seems clear that it will take substantial increases in prices over the levels of the 1950's and 1960's to induce the owners of the available hardwood sawtimber to put it on the market.

Now I want to stress that this is the outlook if we do not intensify management. With better management, U. S. timber supplies, in time, could be dramatically increased. The growth attainable in fully stocked natural stands is approximately double what we are averaging today. Through the use of genetically-improved planting stock, fertilization, moisture control, and the best spacing and thinning techniques, we could go much further, but no one knows the attainable limits.

There are opportunities for intensifying management on all ownerships and in all sections of the country.

The National Forests, and particularly those in the West, have the capability of supporting much larger harvests and doing so in the near future. Through additional investments in reforestation, stand improvement, road construction, thinning, and salvage, it would be possible to increase timber harvests fairly quickly from the old growth stands which compose much of these public holdings in the West.

Growth on industry lands in all sections of the country is much below what can be achieved in fully stocked natural stands. So the forest industries also have an opportunity to increase timber supplies by intensifying management.

From the national standpoint, the biggest opportunity to increase timber growth is on the 59 percent of all commercial timberland--296 million acres--in farm and miscellaneous private ownerships. We recognize that many of these lands are held mainly for recreation, speculation, or other nontimber objectives and that management efforts for timber are limited. Average growth per acre is 36 cubic feet--considerably below reasonably attainable levels. Expanded programs of technical assistance and financial incentives to increase planting, timber stand improvement, and other management practices could, in time, result in substantial increases in the Nation's timber supply.

In closing, I would like to summarize what I have had to say as follows:

Several recent studies have shown that timber markets in the U. S. are likely to grow rapidly in the decades ahead. Although part of the increase can be met by improved utilization and increases in net imports, the potential gains are relatively small in comparison to the total growth in timber product demands. The best opportunity for increasing supplies is through intensified management of our domestic forests. There are opportunities for intensifying management on all ownerships and all regions of the country. The Nation's forest lands have the capability under intensive management of growing at least twice the volume of timber produced today.

LET'S CALL THE WHOLE THING OFF!

by Gordon Baskerville, Department of Forest Resources, Faculty of Forestry, University of New Brunswick.

The organizers of this symposium assigned me the task of the devil's advocate. My job is to convince you that we either do not need to increase wood yield or cannot do it. Clearly they did not have much faith in my oratorical abilities because they have scheduled no less than 32 speakers to follow me, each dealing with a specific aspect of how to get on with intensive management. It is unlikely indeed that I would succeed in having the symposium cancelled as unnecessary and my title is admittedly facetious. However, I do have a deadly serious point to make. Simply stated my point is that as a profession we have been largely ineffectual (perhaps even to a degree, irresponsible) in the promotion of intensive forest management in the northern forest and that this will continue until we modify our approach. It would be most appropriate to begin here in the next two days.

To develop my point let us start with this symposium. The papers this morning are intended to rationalize the need for intensive forest management - literally to justify the real discussion which is to follow. The papers of the symposium proper are essentially of the familiar technical "how to" form. Clearly we are here to talk about getting on with the job because to us it is abundantly clear that there is a job to be done. Since we already seem to have decided we will do the job it might perhaps be useful to establish what "the job" is. I have sufficient experience in the northern forest to permit me to believe we could indeed carry out the various silvicultural manipulations we will discuss here. That is, technologically they are all feasible operations. What is not at all clear in my mind, and judging from the press and our technical journals apparently in a substantial number of other people's minds, is why we would do them.

Sounds heretical - not really. Do we as a group have a clear idea of the goal of intensive forest management? Of course we do - its the management of the forest, through the application of silviculture, to achieve the greatest good for the greatest number. But is that clear? Would we know when we reached that point? Is it in fact a goal at all? There are many benefits that flow from the forest - pulp and paper, lumber, aesthetics, wildlife, social, water, environmental quality and recreation just to name a few categories. If we conceive of the flow of benefits as a pipe and each of these categories as a faucett on the pipe then it is clear that opening any faucett reduces the flow to others. Thus the goal as just stated implies optimization of all benefits. That is, a consideration of the setting of all faucetts. But do we really mean this? In this symposium only two papers deal with "other amenities" while 95% of our discussion will be concerned with the production of wood.

Obviously we cannot expect to be credible on the motherhood goal of intensive forest management. In fact, if we are honest, we have no desire to attempt to inflict our relative values of the various categories of benefits on society at large. We would prefer that society somehow make these tradeoffs and then we will manage the forest so as to produce the desired mix of benefits. How about limiting the goal of intensive forest management to obtaining the greatest possible flow of wood from the forest consistant with maintaining the flow and other amenities? Sounds better and it is directly related to our professional talents, but is it necessary? Is it realistic?

As I drove to Orono I passed through miles of forest on both sides of the border that certainly are not under intensive management by anyone's definition. A frighteningly large proportion of the recent cutover does not even appear to support a reasonable mix of useable species by current standards. There are two possible explanations for this observation. First it may be that we do not need more wood because we are not cutting the full allowable cut there is no need to manage intensively. Secondly it could be that we really do need more wood but the foresters responsible for management are incompetent. Since I am unwilling to accept the second alternative as true, I conclude that there is really no need to maximize wood yield. Intensive management means expenditure of money and manpower and we would not really expect a landowner to spend money on intensive management to produce more wood that he doesn't obviously need. In fact a manager who would spend money in such a way would not be considered responsible in our society.

Historically this line of reasoning appears to have left our profession trying to sell intensive management in a rather poor market. Also historically we have talked about 'good' or 'better' forest management, meaning intensive forest management, and have regularly implied that all silviculture is 'good'. We have used the word management so loosely as to all but destroy its meaning. The phrase intensive management implies something beyond ordinary management yet we have not been explicit as to what constutes management and what level of increased input constitutes intensive management. Further, our arguements for the implementation of intensive forest management are heavily laden with value judgements about the inherent virtues of 'good' management of the forest. One need not look far in northeastern North

America to see that these arguements have not been convincing to the landowners. You have to search dilligently to find that part of the forest that is intensively managed.

A major problem has been that rather than manage, the traditional approach in forestry has been to adjust utilization standards. When the 18 inch white pine suitable for sawlogs were gone it was more expedient to harvest smaller pine and 12 inch spruce than grow large pine by intensive management. When the large spruce are gone we utilize smaller spruce and balsam fir. With pulpwood we have seen a similar change in acceptable species and sizes. Such changes result in an instantaneous increase in useable wood and are often regarded as 'good' or 'better' management whereas the culture of a forest requires time and money which are regarded as long term investments. Perhaps the ultimate in this progression will be reached when all the tree species have been high graded out and we meet our industrial needs with something akin to Harold Young's puckerbrush paradise. We can do this without intensive management, indeed, since changing utilization standards is an immediate solution it obviates the awkward necessity of a time delay associated with management. Such an approach bears little or no relationship to the notion of planned forest management.

As a group, foresters tend not to look analytically at why there is so little 'good' management (i.e. intensive) but rather seek to promote the concept by incentive programs or policy changes. By implication we are saying that since people do not see the inherent good in silviculture and intensive management, we will pay them to do these 'good' things for themselves or make them a matter of policy. I have become cynical about such approaches. Incentives and policies as sole tools for promoting intensive management at best engender lip service and at worst result in callous tokenism. If we can only achieve intensive management by paying people from public funds or by decreeing it, and I do not underestimate the value of these, we can hardly expect a very comprehensive or vigorously pursued program. Surely if we have a valid point with respect to intensive management we can make it without buying or decreeing belief.

Experts in the field of social psychology have told me that foresters are outstanding in their free use of value judgements. This is perhaps most obvious with respect to intensive management and its associated silviculture. These are always considered as 'good'. Yet there are many with an interest in the forest who do not see or do not want our particular kind of 'good'. As a result we regularly find ourselves bogged down in endless unresolvable arguements over perceived values with all the moralistic implications this involves.

Can we, in the next two days, continously bear in mind that intensive management and silviculture are amoral. They are simply concepts and acts that possess no inherent virtue. We do not do these things (nor advocate them) because they are 'good' or 'better', we do them because they are essential to achieve certain desirable ends. If intensive management and silviculture help us to reach our goals then they acquire goodness and of course the opposite is true. That is, intensive management and silviculture are good (or bad) only when considered in relation to our goals.

I believe there is ample evidence that our usual broad motherhood goals are inadequate to our needs. If we persist in using meaningless phrases open to many interpretations, the profession will lose its already dwindling credibility with respect to forest management. Whether we actually have control of forest management or not, we are considered to be 'the managers' of the forest and if the results of 'management' (whatever intensity) are found to be seriously lacking we - and perhaps, but not necessarily, our masters - will be publicly held to blame.

We must have explicit goals for management and we need a willingness to stand up and take a public position when our masters (political or private) accept goals but don't come through with the dollars and manpower to do the job. We have all seen acknowledgements by public and private agencies that they subscribe to good forest management. We have also all seen how most of these agencies are unwilling to dedicate the resources necessary for more than token efforst towards such laudable, but imprecise, goals. Can measurable goals be set? For a given forest an explicit goal can easily be set for yield - say 300,000 cunits per annum - rather than use the vague indeterminate notion of maximum yield. Given such a goal one can readily determine if it will be met without any management and, if not, the management steps essential to meeting the goal can also readily be determined with current technology. Most importantly, such a goal is attainable and we will know exactly when it is reached. If the dollar support for the necessary programs is not there this will also be evident and the short fall will be a finite amount rather than just 'not enough'. Note that with such an explicit goal you do not necessarily invoke all the tricks in the bag called intensive management, another general implication of which we are frequently guilty. You only need to gear up and spend dollars on the techniques essential to reaching your goal. As progress is made the goal can be raised and more sophisticated methods introduced.

As an example of goal setting let me suggest that growing more volume may not be what it is all about. In much of the forest we are discussing, we still face the problem of oversupply and the philosophy that we don't need technical management because when we run out of trees we can use puckerbrush. But there is one major problem that can only be solved by application of some intensive methods. It may not be widespread in the Northeast, but in Atlantic Canada we have what is most simply termed a quality problem. For example in New Brunswick our harvest of hardwoods is less than one - half the allowable cut and our harvest of softwoods is just reaching the calculated allowable cut - based on volume. Perhaps more particularly in the hardwoods but also in the softwoods, we are discovering that an under-cut in terms of volume can easily be an over-cut in terms of quality. That is, we still have plenty of volume but it is made up of trees of poorer quality than we have harvested in the past. While this is not well documented we often hear industrial managers decry the faltering quality of the forest yield.

The reasons for this situation are somewhat complicated, but simply stated they relate to our past solution of management problems by lowering utilization standards and the fact that if you want a big tree of high quality you must let it grow for the time it takes to get to the desired size. We are discovering that regulation by volume does not always allow for sufficient time to reach what we consider a desirable size! There is an alternative to just waiting - we can use techniques of intensive management to get the quality we desire sooner and to concentrate the quality material spatially. In the case of New Brunswick while we cut only 47% of the allowable hardwood cut, there is an urgent (perhaps the word is desperate) need for intensive methods in part of the hardwood forest to maintain a flow of suitable quality wood. I suggest that intensive management may have greater justification today for producing quality than for producing quantity. The goals for quality can be stated explicitly in terms of amounts, sizes and quality parameters and it is therefore possible to determine readily what must be done to reach those goals.

If we want to see intensive management practiced (i.e. to have our talents used) then we should not ask that it be done simply because it is good to do so. We must extract goals from the owners and then show what must be done to meet these goals. This can be presented in the form: if you want this goal, then you must carry out this intensive management, or conversely, if you don't manage in this manner then you will not meet your goal.

The goals can be many and varied. They include quality and quantity of wood, location, and even attaining amenity values. But we must insist that the goals be made explicit so that our proposed management schemes can be properly designed and assessed.

To go back to the beginning - if we continue to try to sell intensive management as a 'good' solution to all ills (real and imagined) I do not believe we will ever be successful. In fact the chances of being convincing in this way grow slimmer every year. On the other hand if we extract reasonable quantifiable goals from the forest owners (private and public) then we can demonstrate that a given mix of intensive management methods is essential to reach those goals - and we might find ourselves actually managing the forest. There is no doubt in my mind that we need a more intensive approach to forest management. It disturbs me that we are not getting it and that a major part of the problem is our predilection to discuss the means as if they were the ends.

As a devil's advocate this is perhaps a positive note on which to end but while I do feel strongly that silviculturists have not served their purposes well I am quite human and don't practice what I preach. I must say I would rather have talked to you about my work in spacing and early thinning in softwoods because like all of you, I want to get on with the job.

PRESENT METHODS AND TECHNOLOGY AVAILABLE FOR INTENSIVE MANAGEMENT AND EXTENT OF PRESENT USE

by Gordon F. Weetman, Associate Professor
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Abstract

While there have been major technological developments in regional agriculture and forest harvesting and in intensive forest management in the Southern pine region and the Pacific Northwest, the application and development of intensive forest management has lagged in the Northeast.

Some of the characteristics of low, medium and high yield forestry are presented and recent developments in operational and managerial technology are reviewed.

It is concluded that we do have operational "hardware" for more intensive forest management, although mechanization could be further advanced. However, we are often lacking in the decision making "software", particularly at the 'whole forest' level, in order to account for the many factors which dictate which of the management options are appropriate. The northeastern forest, particularly the hardwoods, seem best suited to medium yield management for stand quality. The need for suitable financial incentives is stressed and attention is drawn to the important human and institutional problems that must be considered.

SINCE OTHER SPEAKERS are reviewing some of the techniques used in intensive forest management in some detail, the purpose of this paper is to briefly review each of the present techniques available for use and identify those which have developed rapidly in the last ten years,and note their relevance to conditions in the Northeast. The paper will have an understandably Candian bias. The N.E. region, I assume, covers those States belonging to the Northeastern Region of the U.S. Forest Service plus the Maritime Provinces.

We live in a technological era, and while we have all noted the dramatic changes in agriculture (Schebecker 1975) which have produced the so-called "green revolution", and we have also seen dramatic changes in the development of forest harvesting techniques, there have been relatively few dramatic developments in technology in the growing and management of forest crops in the Northeast. I will not dwell on the social, economic and geographic reasons for lack of intensive forest management in the region; suffice to say that the application of technology to the region is compounded by such problems as terrain unsuitable for mechanized equipment, low quality and non-uniform stands composed of several species, many of which have low market values, and land ownership patterns and history of land use unfavourable to investment in forest management.

The major developments in technology for intensive forest management are being developed either in the Southern pine region or in the Pacific Northwest, or are direct applications of spinoffs from the developments in agriculture. The technology presently available will be considered under two headings: Operational and Managerial. (See Table 1).

OPERATIONAL TECHNOLOGY

The region is not characterized by major investments in plantation forestry. Historically forests have often been 'high graded' for quality species stands and logs. Initial efforts of improved management have usually called for judicious partial cuts for timber stand improvement, or shelterwood cuts or modified clear cutting, all with reliance on natural regeneration. However, it is in plantation forestry where there have been dramatic technological changes. Research in forest genetics and cooperative forest tree improvement programs in the Southern United States and elsewhere have led to the massive production of genetically improved tree seed (Zobel 1976). The economic benefits of such programs can only be realized through artificial regeneration. While there is little doubt that the techniques of forestry improvement, if applied to the Northeastern tree species, would produce economically attractive changes in stand volume, quality and vigour, the application of this technology has been quite limited due to the lack of reforestation programs (Carlisle and Teich 1971, Carlisle and Ottens 1976). There has been local interest in hybrid poplar production for short rotation management (Anderson and Zsuffa 1975) and in the use of certain exotics, particularly larches (Cook 1975). While research workers continue to investigate the genetic variability and heritability of the Northeast species and conduct provenance trials and trials of exotics (Fowler 1976), at the operational level practice is limited to the usual precautions regarding seed collection zones, seed collection procedures and the identification of phenotypically superior stands for seed production. Good guides are available for the collection and handling of tree seed and mechanization of collection is developing.

There have been periodic enthusiasms for direct seeding because of its apparent low cost and ease of application. Two symposia have been held (Abbott 1964, Cayford 1974). At the operational level the track record has been grim. There have been local successes and it is used for jack and lodgepole pine in the boreal forest, but even the technology developed for chemical seed coatings

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tic bullets and biodegradable containers on a very large scale at relatively low cost to large sizes and all in a few months instead of two to four years in conventional nurseries. Such container stock production is less robust and calls again for careful site preparation and is very suited for mechanized handling and planting systems. Special high production planting machines are being developed and bullets are being 'bombed' from planes.

Site preparation for either seedbed preparation, or for planting, has developed very rapidly outside the region. It is now possible, provided a tractor can traverse the ground, to treat very large acreages at relatively low costs, using front or rear mounted equipment on the tractor, suitable for direct seeding, or for natural seeding or as suitable sites for planting operations.

The application, however, again is limited in this region to a few locations. The 30,000 plus acres of spruce plantations in northern New Brunswick were established by the Irving organization using a Letourneau tree crusher for site preparation in one such example. However, the large block of privately owned land and the gently rolling, relatively stone free soils of the area represent a rather unusual combination of favourable conditions.

Control of vegetative competition through the use of auxin herbicides such as 2,4-D and 2,4,5-T and chemicals such as atrazine and simazine and cacodylic acid are also well established technonologies, which can be effective and are in cases absolutely essential, for successful stand establishment. However, enthusiasm for their use has been considerably dampened by concerns about their environmental effects. The literature in this area is enormous, but on balance it does appear that, as in agriculture, the use of such chemicals to control vegetative competition is often the only feasible way of getting the job done and that the environmental risk is acceptable, especially for the auxin herbicides (Newton 1975, Newton and Norris 1975).

Pre-commercial thinning of excessively dense young stands has received a lot of attention recently (Porterfield and Schweitzer 1975). It is widely practised outside the region and is one of the most attractive areas for investment in forest management because it controls spacing, vegetative competition and species composition and produces stands of high mean diameters on shorter rotations. It is nearly all hand labour using either power saws or special brush saws. It has resisted, and probably will continue to resist, all attempts to mechanize it (Dunfield 1974). Even the use of tree killing chemicals, such as cacodylic acid, has fallen into disfavour. The high labour content, the relative ease of application and its almost year-round application made it an attractive investment for government agencies in areas of high unemployment.

Forest fertilization is an operational technology in the South, mainly using phosphorous, and in the Pacific Northwest and Scandinavia, using nitrogen. It has attracted a lot of research, it works in the right situations. It uses expensive fertilizers and it is of doubtful economy for low quality stands, or a low value species. Whether or not nitrogen fertilization of Northeastern tree crops can match the economic returns and priorities for fertilizer use in agriculture crops is questionable. Forest fertilization is also a favourite topic for symposia, one recent in this region (Northeastern Forest Soils Conference 1973). It does appear that fertilization is the frosting on the top of the total forest management cake and without the cake there is little economic justification for the frosting. The environmental hazards involved appear to be acceptable, based on present information.

I am reluctant to blow any cobwebs off the hoary old questions surrounding the application of commercial thinnings. All over the western world, and this region is no exception, high labour costs and shortages of manual labour for hard physical work, have greatly reduced the application of the beautiful and rational thinning regimes designed to recover mortality and improve stand quality. Present trends are to grow trees at wide spacing and on short rotations and thus avoid thining (Buckman and Newton 1972). The dramatic changes in the technology of logging has in some instances led to the development of special mechanized equipment for thinning, especially in plantations. However, outside of plantations, such machines have little application in this region, mainly because of low stand quality and excessive stand densities. Of much more pragmatic significance for the region is whether or not it is feasible for certain types of stands to carry out partial removals of the stand, which can be designated either as thinnings or partial cuts or shelterwood cuts, using rubber-tired skidders and either short wood or tree length methods. It can be done and is being done, for example, on the holdings of the Seven Islands Land Company in Maine, but does require great care on the part of the cutter and the skidder operator. This technology and this practice is very appropriate to the region and controversy exists as to whether it is possible to mechanize the operation further to remove the undesirable and unpleasant labour aspects involved, without losing the flexibility, low cost and ease of applicability.

There is also concern about the mechanization of logging. Sophisticated new machinery for tree length and whole tree harvesting, with high operating costs, limited operational flexibility, requires high quality stands. Advance growth may be destroyed, forests may be high graded and environmental problems involving physical and chemical damage to the soil may develop. Whether or not this technology favours or hinders intensive forest management is dependent upon a commitment to intensive forest management and a clear set of management objectives. In many cases this technology has invaded the forest without allowance being made in management planning, in increased investments and in adjustments in cutting schedules, allowable cuts and the application of the appropriate management technology to ensure prompt restocking. Often the response has been when in doubt scarify! It is this latter area of decision-making which leads to what I consider to be the crux of the whole affair and that is

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This has been an area of major technological change, because while historically we could handle much of the operational technology to carry out intensive management, we were not in a position to justify expenditures of money in order to make due allowance for uncertainty of yields and biological variability. The application of intensive forest management elsewhere in North America has been justifiable at the industrial level, mainly because it works biologically and it was possible to quantify the benefits. The shorter the rotation and the less biologically complex forest, the easier this job becomes. There is a new technology of forest resource decision making. A new textbook in this area which is now widely used in many North American forestry schools by Duerr et al (1975) is symptomatic of the change. Computers have made a great many changes in our lives. There is a theoretical and to a certain extent applied technology using stand

and tree growth simulation models which does permit the estimation of yields of forest stands by age, species, site class and density, with outputs in terms of tree size, volume, biomass, tree quality and age initiation of mortality (Fries 1974). Forest inventory procedures have been completely changed. Analyses of growing stock by stands, allocation of cuts, inputs from social and economic factors are now analyzable and to a reasonable degree quantifiable for whole forest systems (Navon 1971, Ware and Clutter 1971, Alston 1972, Hoyer 1975, McDonough and Park 1975, Lussier 1976). For large corporate forest holdings and for large public forests, analyses of this type now permit a rational examination of the benefits of intensive forest management. One of my favourite examples of this type of an approach in intensive forest management is that of the Swedish Cellulose Company which has stand development and silvicultural decision models, which indicate for various site classes and stand conditions those locations most appropriate for intensive management investments (Hagner and Fries 1972, Hagner 1974). The Weyerhauser corporation is very advanced in this technology, with its 'target forests' and $5,000,000 annual forest research expenditure (Mitchell and Roberge 1974).

While this technology will handle a lot of the figuring, there is still the on-the-ground problem of soil fertility and site variability. Intensive forest management calls for decision making which locates on the ground, sites most suitable for treatment and which indicates how such treatments will relate to other forest land uses, such as wildlife, recreation, watershed values, etc. The prescriptions cannot be oversimplified (Smith 1975). There have been troubles in this area, environmental troubles when forest management technologies are blindly applied, while ignoring these values. Again a system is called for. I feel we have made progress in this area. In Canada we have a biophysical land classification system which permits, through the use of appropriate inventory techniques by specialists in ranking and rating of land capability and the rational integration of land uses (Jurdant 1969). Such ecological approaches permit a rational framework into which decisions regarding intensive forest management can be incorporated. There are so called "folio" approaches to resolving some of these complex problems (Bullen 1975) and there are new inventory procedures designed to collect the appropriate information of all the resource values. Here in the U.S. my understanding of the situation is less clear. The philosophical and operational procedures are different. The decision making centres around soil mapping by the Soil Conservation Service and other agencies followed by woodland interpretations. There has been an emphasis on predictive equations to relate yield to measurable soil parameters.

Our improved understanding of growth and yield and the silvics of the species, together with our analytical capabilities in forest economics, have given rise to a series of very useful bulletins and guides for intensive forest management. For example, the Ontario Silviculture Guides for Working Groups and the Spruce-Fir and Northern Hardwood Guides produced by the Northeast Forest Experiment Station indicate appropriate tending and harvesting procedures for different stand ages and stand conditions. Other reports indicate economic returns and methods of analyzing the results of various management practices. These bulletins are not decision making models for management but they do provide most useful information when management decisions are needed. It is now technically possible to develop a complete system for decision making in the application of intensive forest management.

APPLICATION OF TECHNOLOGY

Table 2 outlines the characteristics of low, medium and high yield forest management. While we apparently have the operational technology to conduct any of the three options, i.e.,'the hardware' to do the job; I feel that we lack the decision making 'software' to decide on which option, at which locations and at what level of intensity. Rather than follow the usual pattern of opting for low yield forestry with declining utilization standards, I feel there is a good case to be made for the middle option in the N.E. - an emphasis on stand quality rather than quantity - particularly for the hardwood species. The emphasis here is on directing the natural forces of competition and selection rather than establishing an maintaining an artificial forest crop.

Much of the work that has been done in developing high yield, intensive management systems and decision making procedures during the last few years has been done by large corporations or big government. This body of technology is essential if decisions on major investments in intensive forest management are to be made on some rational basis. Many of the areas are quite complex, require considerable capital investment and a high degree of expertise in their application. The benefits which accrue from such investments, particularly when rotations are long, are difficult to justify for smaller forest holdings. The Northeast region is characterized largely by smaller ownerships and much of this new technology for intensive forest management is thus very difficult to apply, but it has been done in other countries, as for example, Finland and Norway. Also, most of the technology is best suited to growing relatively intolerant trees in plantations. Much of it is ill-suited to tolerant trees, particularly hardwoods. Stand conversion is usually required.

It is interesting to note that in Eastern Canada much of the funding for intensive forest management, where it is practised, has come from government agencies which have been motivated by social reasons. There is a powerful argument for government subsidies, tax incentives, etc., for intensive forest management which will give rise to improved local employment and better quality forests, which in turn will attract capital investment for forest industry. In some cases the pressure for this type of funding has come from the rural residents and not from large corporations or government planners. In my view we do have existing and workable technologists to practise intensive forest management now but their application is constrained by lack of management systems and lack of suitable financial incentives provided by government (Skok and Gregersen 1975, Weetman 1976). While we must continue to work on improving our technology and reviewing our progress in intensive management in symposia such as this one, we must not ignore the human and institutional problems and attitudes which must be changed if we are to put intensive forest management into practice.

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TABLE 1.

TECHNOLOGY FOR INTENSIVE FOREST MANAGEMENT IN NE

OPERATIONAL

- Seed Production Areas (1)
- Seed Orchards
- Seed Treatment
- Direct Seeding
- Seedbed Preparation (1) (4)
- Site Preparation (1) (3) (4)
- Conventional Nursery Stock Production (2) (3)
- Container Stock Production (1) (3) (4)
- Herbicide Control of Vegetative Competition (1) (3)

- Modified Cutting (2)
- Planting Mechanization (1) (3)
- Pre-Commercial Thinning or Spacing Control (1) (3)

- Timber Stand Improvement (1)
- Thinning (1) (3)
- Pruning (1)
- Fertilization (3) (4)
- Spraying and Cutting to Control Insects and Diseases (2) (4)

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(1) Used in NE on Limited Scale
(2) Used in NE on Extensive Scale
(3) Technology Well Developed and Used in Other Regions.

(4) Important Recent Developments in Technology.

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- Ecological Surveys for Integration with Other Forest Uses and Choice of Sites, Species and Degree of Effort (1) (4)
- Improved Data Collection in Forest Inventory for Analyses of Stand Conditions and Growth Rates (1) (3) (4)
- Soil Survey and Site Index Studies for Fertility Estimates (1) (3)
- Managed Yield Tables Giving Volume Production by Species, Site, Density and Rate of Mortality or Thinning (1) (3) (4)
- Silvicultural Guides for Species Working Groups and Stand Conditions (2)
- Stand Simulation and Optimization Models Giving Production and Economic Returns from Different Management Practices and Strategies (1) (3) (4)
- Whole Forest Models Analysing Various Socio/Economic/Ecologic Inputs and Strategies (4)
- Production and Performance Models and Decision Making Tools for Choice of Operational Equipment and Methodology (2) (3)
- Studies of Effects of Changing Utilization Standards on Rotation Lengths and Usable Yield (2) (4)

TABLE 2.

CHARACTERISTICS OF INTENSIVE FOREST MANAGEMENT OPTIONS

Option	Energy & Dollar Inputs for Management	Expertise & Capital Required for Management	Application to NE	Provision of Stable Rural Employment	Technology Available?	Decision Making Tools Needed
1. High yield plantation forest - removal of original forest cover - site preparation - use of genetically improved stock - short rotations - emphasis on stand quantity & quality - mechanized operations	high	high	limited by trafficability	may be limited by expertise & mechanization required	for some species & sites	- site fertility equations - sophisticated forest inventory - managed yield tables - economic analysis of operations - a total system for management - monitoring and analysis of performance
2. Medium-yield forests - limited logging mechanization - modified cutting - seedbed preparation - natural regeneration or limited planting - precommercial thinning - longer rotations - emphasis on stand quality	medium	medium	suitable for many sites & species	good potential	for some species	- workable ecological classification - managed yield tables - inventory by stand condition - estimates of "additional" costs of operations - management system & field guides
3. Low-yield forests - lowest cost logging - often heavily mechanized - natural regeneration - stable or declining stand quality	low	low	widely applied now	limited	readily available	- inventory of commercial operable timber - a method to choose lowest cost logging operations - monitoring of stand quality & quantity

HOW APPLICABLE IS EVEN-AGED SILVICULTURE IN THE NORTHEAST?

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Abstract

The applicability of even-aged silviculture in the management of forest stands in the Northeast is examined through consideration of the forest stand, stand development, intermediate cuttings, and regeneration methods. It is concluded that even-aged silviculture is quite applicable in the management of forest stands in the Northeast.

Experience has taught me that rational discussions of silvicultural practices require mutual understanding of standard terminology. I have had on occasion the frustrating experience of continuing a somewhat heated discussion regarding a particular silvicultural practice with a colleague only to realize eventually that we were in complete agreement but were using different terminologies. To avoid such an occurrence here, I shall give particular attention when warranted to terminology in answering the question, "How applicable is even-aged silviculture, i.e. the growing of timber crops in even-aged stands, in the Northeast?" Furthermore I have organized my answer in what seems to me to be a logical approach by considering the forest stand, stand development, intermediate cuttings, and regeneration methods.

FOREST STAND

The forest stand is defined as being "a community of trees possessing sufficient uniformity as regards composition, constitution, age, spatial arrangement and/or condition to be distinguishable from adjacent communities so forming a silvicultural or management entity" (Society of American Foresters 1971). I should like to emphasize (1) that a forest is composed of forest stands, each occupying a specific area on the landscape and reflecting the sum total of the time period and environmental conditions under which it has developed, (2) that forest stands, having developed under different time periods and/or environments, differ recognizably one from the other in one or more attributes and (3) that forest stands, because they differ one from the other, may require different silvicultural treatments to attain given objectives of management and therefore, form the basic units of silviculture. Professional foresters examine forest tracts, write silvicultural prescriptions, and impose silvicultural treatments stand by stand.

Forest stands are classified depending on their constitution, i.e. the representation and distribution of age and/or size classes, as being either even-aged or uneven-aged. Even-aged stands are composed of trees having no or relatively small differences in age. By convention, the maximum age differences admissible is generally 10 to 20 years, however, with rotations of greater than 100 years, differences up to 30 percent of the rotation may be admissible. Uneven-aged stands are composed of intermingling trees that differ in age more than is admissible for the stand to be classified as an even aged-stand.

Forest stands that originate following the destruction and/or removal of forest vegetation, whether by natural causes or man's activities, usually do so quite rapidly and are almost always even-aged. Forest fires, hurricanes, floods, insect and disease epidemics, timber harvesting, and the abandonment of crop and pasture lands have provided and continue to provide excellent opportunities for even-aged stands to become established. As pointed out by Smith (1972), foresters have repeatedly found the establishment of even-aged stands following major catastrophes to be a most common phenomenon.

Forest stands are also classified on the basis of composition, i.e. the representation of species in a stand expressed quantitatively as percent by number, basal area, or volume. Stands in which 80 percent of the trees forming the main crown canopy are of a single species are classified as pure stands. Stands failing to qualify as pure stands are classified as mixed stands. Pure stands are less common than mixed stands because sites favorable for the natural establishment and growth of only one tree species occur infrequently in nature (Baker 1950).

Since no two species have exactly the same pattern of height growth with respect to time, the main crown canopies of many even-aged mixed stands tend to become stratified vertically into more or less distinct layers (Smith 1972). In such stands, the crowns of the faster growing, more intolerant species occupy the uppermost layer of the crown canopy; the crowns of the slower growing, most tolerant species, the lowermost layer; and the crowns of species intermediate in growth and tolerance, if present, the middle layer. Stands of this type may appear to be uneven-aged but upon close examination are usually found to be even-aged. Mixed even-aged stands growing on good sites are usually quite productive and may provide the forest practitioner with a variety of management options, however, they are probably managed most effectively as even-aged stands.

STAND DEVELOPMENT

Nondormant viable seed of all tree species germinate and produce established seedlings only on well-aerated, moist seedbeds under favorable temperatures and sufficient light. Consequently, natural seedbeds tend to be either very favorable or very unfavorable for germination and seedling establishment. Unfavorable seedbeds fail to become stocked with even a single seedling while favorable seedbeds become stocked with an excessive number of seedlings. Thus, even-aged stands and small even-aged groups of trees in uneven-aged stands begin life too densely stocked for individual seedling to grow for long entirely free of competition.

As a young stand begins to attain full occupancy of the site competition among trees for water, light, and nutrients intensifies both above and below ground, branches near the ground begin to die, and the trees begin to differentiate into crown classes in accordance with their relative ability to grow in height. The stronger, most vigorous individuals forge upward to occupy dominant and codominant positions in the crown canopy. The weaker, less vigorous individuals fall behind to occupy initially intermediate and later overtopped positions in the crown canopy where they are destined eventually to die. As the stand grows into the pole stage, competition becomes increasingly more intense, crown classes become more distinct, losses of trees due to suppression and death reaches a maximum, and natural pruning produces progressively longer branch-free boles and shorter crown lengths. By the time the stand has attained its maximum height for the site, competition has reduced the crown size of most trees below that required for them to remain vigorous and the stand begins a long period of slow growth followed by a period of deterioration. Thinnings begun early in the life of the stand and repeated as needed would have increased the yield of merchantable wood, maintained the vigor of the crop trees, and lengthened the productive life of the stand.

INTERMEDIATE CUTTINGS

An intermediate cutting is any cutting made in a forest stand between the time of its formation and the first regeneration cutting. Intermediate cuttings are conducted in immature forest stands with the two principal objectives of (1) enhancing the value of existing stands by controlling the composition, density, and growth through all stages of stand development and (2) increasing the total yield of stands by utilizing all of the merchantable wood produced during the life of the stand. Intermediate cuttings differ from regeneration cuttings in that no effort is made to secure regeneration and the creation of permanent openings in the crown canopy is carefully avoided.

Eight different kinds of intermediate cuttings, each designed to accomplish a particular purpose, are recognized as follows: (1) weeding (2) cleaning (3) liberation cuttings (4) thinning (5) improvement cutting (6) salvage cuttings (7) sanitation cutting and (8) pruning (Smith 1962). Weedings, cleanings, and liberation cuttings are conducted in stands not past the sapling stage of development to release desirable growing stock from the competition of herbaceous and woody vegetation. Improvement cuttings are made to improve the composition and quality of mixed stands past the sapling stage of development by removing trees of undesirable species, form and quality from the main canopy. Thinnings, made primarily to control the density and growth of stands, are conducted periodically as needed throughout all stages of stand development. Salvage cuttings to utilize merchantable wood in trees killed or injured by injurious agencies and sanitation cuttings to prevent the spread of insects or diseases are conducted as required throughout the life of the stand. Selected crop trees of species that produce lumber commanding a premium when free of knots may pruned to improve the quality and value of wood produced.

The judicious application of intermediate cuttings provides the best means of increasing the yield and quality of merchantable wood produced by a forest stand. Intermediate cuttings are as applicable in the management of uneven-aged stands as they are in the management of even-aged stands. However, the need for an intermediate cutting is more easily recognized and intermediate cuttings are more economically applied in even-aged stands than in uneven-aged stands.

REGENERATION METHODS

A regeneration method is the procedure by which a mature forest stand is harvested and replaced with a young stand. A regeneration method includes not only the removal of the mature stand in such manner as to create, in so far as it is feasible, environmental conditions conducive to germination and seedling establishment but also any cultural treatments of the seedbed that might be required to ensure rapid replacement of the old stand by an adequately-stocked young stand of desirable tree species. Various methods of establishing even-aged forest stands from seed have found application, however, any given method can usually be classified under one of three standard regeneration methods each of which denotes distinctly different principles (Smith 1962). The three standard regeneration methods of establishing even-aged forest stands from seed are the clearcutting method, seed-tree method, and shelterwood method as defined below.

Clearcutting Method

In the clearcutting method, all trees on an area to be regenerated are removed in one cutting with regeneration of desirable tree species being subsequently obtained either naturally from seed disseminated over the cutting area from adjacent forest stands and/or from trees removed in the harvesting operation or artificially by either planting tree seedlings or sowing seed on the cutting area.

Natural regeneration of a clear-cut area is usually either wholly or impart dependent upon seed disseminated naturally by wind subsequent to the removal of the mature timber, therefore, no portion of the clearcut area should be more distant from seed-bearing trees of the species to be regenerated than the distance to which the seed can be disseminated in sufficient quantities to produce adequately-stocked stands.

Seed-Tree Method

In the seed-tree method, all trees on an area to be regenerated are removed in one cutting save for a small number of seed-bearing trees, usually from one to ten trees per acre, retained either singly or in small groups to provide seed for the subsequent natural regeneration of the area. Following the establishment of adequate regeneration, the seed-bearing trees may be removed in a second cutting or left indefinitely. Since under the seed-tree method of regeneration, a seed source is retained on the cutting area, the size of the cutting area is not limited as it is under the clearcutting method.

Shelterwood Method

The shelterwood method involves the removal of all trees from the area to be regenerated in a series of cuttings extending over a period of years equal usually to no more than one-quarter and often not more than one-tenth of the rotation with the establishment of natural regeneration of desirable tree species being obtained under the partial shelter of the parent stand. Regeneration of a previously untreated mature stand by the shelterwood method may require three different kinds of cuttings namely, preparatory cuttings, seed cutting, and removal cuttings as defined below.

Preparatory cuttings. Preparatory cuttings are cuttings made to prepare dense mature forest stands, under which regeneration of desirable tree species has failed to become established for regeneration by (1) removing defective trees and trees of undesirable species (2) improving the vigor, seed production, and wind firmness of desirable tree species and (3) increasing the rate of decomposition of thick humus layers that tend to preclude the establishment of natural regeneration.

Seed cutting. The seed cutting is a cutting made in a mature forest stand to create permanent openings of sufficient size in the crown canopy to permit heat, light, and moisture to penetrate to the forest floor in amounts required for germination and seedling establishment of desirable tree species. To be most effective the seed cutting should be made during a year when the desirable tree species bear seed in abundance.

Removal cuttings. Removal cuttings are cuttings made to remove the remainder of the mature stand. Removal cuttings are commenced as soon as regeneration has become established over a sizable portion of the cutting area and are continued periodically as required to prevent the mature stand from unduly retarding the growth of established regeneration. The last removal cutting (final cutting) is made when all portions of the cutting area have been regenerated satisfactorily.

Regeneration of an under-stocked mature stand under which an abundance of advance regeneration of desirable species has become established may require only one removal cutting to complete the regeneration process. Such a cutting may be classified erroneously as a clearcutting but, in as much as the regeneration has become established under the protection of an overstory, is properly classified as being the final removal cutting of the shelterwood method.

The three methods of regenerating even-aged forest stands differ one from the other in respect to the number of cuttings required to harvest the mature stand and the arrangement of the cuttings on the ground. The arrangement of the cuttings on the ground determines not only the quantity of seed available for dissemination over the cutting area but also the environmental conditions under which seeds germinate and seedlings become established. Thus, the applicability of a particular regeneration method is determined largely by the silvical characteristics of the species to be regenerated. Tree species intolerant of shade can usually be regenerated most effectively by either the clearcutting method or the seed-tree method. Tolerant tree species can usually be regenerated most effectively by the shelterwood method.

Application in the Northeast

The northeastern spruce-fir, northeastern northern hardwood, eastern white pine, Allegheny hardwood, and Appalachian mixed hardwood types occupying an estimated 11, 15, 7, 12 million acres and a substantial but undetermined acreage respectively in the Northeast have persisted through 200 years of exploitation (U.S. Department of Agriculture, 1973). Although other factors have undoubtedly played a significant role, the persistence of these forest types, in spite of the many and various types of treatment to which they have been subjected, can, I believe, be attributed primarily to the relative shade tolerance of the component species. Furthermore, I believe the regenerative response of the forest types over time and the results of research to date indicate strongly that they can be regnerated in even-aged stands by the shelterwood method or some modification of this method as effectively as they can by any other natural regeneration method (U.S. Department of Agriculture, 1973)

SUMMARY

In summary, I would emphasize the following:

1. Acceptance of the forest stand as being the basic unit of silviculture and dutiful observance of stand boundaries place a definite limitation upon the size of the area available for particular silvicultural treatment at any given time.

2. The forest stands with which foresters have to deal tend usually to be more even-aged than uneven-aged in constitution and more mixed than pure in composition.

3. Consideration of the way even-aged stands develop accentuates the need for intermediate cuttings applied periodically to favor the growth of crop trees and to utilize all merchantable wood produced by the stand.

4. The need for intermediate cuttings are more easily recognized and intermediate cuttings can usually be conducted more economically in even-aged stands than in uneven-aged stands.

5. When properly applied the clearcutting, seed tree and shelterwood methods of regeneration produce even-aged forest stands. Intolerant tree species are regenerated most effectively by either the clearcutting method or the seed-tree method and tolerant tree species, by the shelterwood method.

6. The major forest types in the Northeast can probably be regenerated by the shelterwood method or some modification of this method as effectively as they can by any other natural regeneration method.

7. Even-aged silviculture is quite applicable in the management of forest stands in the Northeast.

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HOW APPLICABLE IS UNEVEN-AGE MANAGEMENT IN NORTHERN FOREST TYPES?

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Abstract

For the proper application and practice of uneven-age management, one must consider residual stocking, maximum tree-size objective, and diameter distribution. All three components are described, and it is shown how they fit into a practical package for application in a timber tract.

THE DECISION to practice uneven-age management in northern forest types is usually based on a combination of factors. Although some of the factors are concerned with silvical or ecological requirements of the species or species groups being managed, there often are other overriding considerations.

But first, what is uneven-age management? What are some of the major components of the system?

There are several definitions and descriptions in forestry literature, and I am sure each of us has our own pet way of describing uneven-age management.

An all-inclusive definition of uneven-age management was presented recently at a workshop sponsored by the U.S. Forest Service (1975). I believe it is a good one. Essentially, uneven-age management is the manipulation of a forest for continuous tall-tree cover and the orderly growth and development of desirable trees, through a range of diameter classes, to provide sustained even-flow yields.

It is implemented through the selection system: single-tree selection for mostly tolerant species, or a combination of single-tree and group selection to increase the proportion of intermediate and intolerant species (Berry 1963; Leak and Filip 1975; Roach 1974). Each operation is not only a harvest of merchantable products, but also an improvement cutting and release job to promote the growth of the retained trees and to maintain or enhance stand structure and composition. Managed uneven-age forests are composed of intermingled trees or groups of trees that differ markedly in age (U. S. Forest Service 1973), but no separate age classes are recognized in regulating the yield (Meyer and others 1962).

For the proper application and practice of uneven-age management, at least three basic components must be taken into consideration: residual stocking, maximum-tree-size objective, and diameter distribution based on a q-factor guideline.

The real challenge to foresters is to understand how all three are linked together, and how they affect growth and quality, allowable harvest, operating cycle, timber-stand-improvement requirements, and the entire economic situation.

RESIDUAL STOCKING

Residual stocking is the volume or basal area to be retained after each cyclic harvest for further growth and development. Available data show that total stand growth varies only slightly over a moderately wide range of stocking levels. Cutting mature stands back to about 50 or 60 percent of full stocking is generally adequate for the northern forest types (Frank and Bjorkbom 1973; Leak and Filip 1975; Tubbs 1968). For example, a residual stocking of about 70 to 80 square feet per acre in trees 6 inches dbh and larger is recommended for northern hardwoods in New England.

MAXIMUM TREE SIZE

The largest tree to be retained after each timber harvest under uneven-age management in northern forest types ranges between 16 and 24 inches dbh. Much depends on site quality, the growth capability of the species involved, the accepted rate of return, and the owner's objectives for the tract.

DIAMETER DISTRIBUTION

The third component that is important in uneven-age management is diameter distribution; that is, retaining an adequate number of trees per acre after each harvesting operation. A prescribed residual diameter distribution, of course, determines the residual basal area and volume.

The general procedure for establishing a diameter distribution is to apply a q-factor guideline, usually referred to as q. The q simply refers to the average quotient or ratio between numbers of trees in successively smaller diameter classes. An ideal structure based on the same q-factor throughout all diameter classes is represented graphically by a smooth reverse-J-shaped curve. Q-factors ranging from 1.3 to 1.7 for 2-inch dbh classes have been recommended as goals in uneven-age management (fig. 1). The lower the q, the higher the number and proportion of large trees in the stand. Old-growth stands tend to have a lower q than second-growth stands.

PUTTING IT ALL TOGETHER

Now that we know something about the three essential components characterizing uneven-age management, how do we link them together into a practical package? And, probably of greater interest and concern to you: How is this package applied on the ground?

Many timber managers undoubtedly have been and still are reluctant to accept all this formality behind uneven-age management. They probably have good reasons for this, and I believe the major one is the apparent difficulty in trying to mark the timber tract to a rigid residual diameter distribution. I admit that trying to control the marking to some specified numbers of trees per acre (or basal area) by 2-inch dbh classes is not easy. Actually, it would be impractical, if not impossible, to maintain the perfect diameter distribution indicated by a smooth reverse-J-shaped curve. Really, it is not necessary to be that exact. The structure represented by the curve is only a guide. But you should not stray too far from it so as to be assured an even-flow of products, especially the large-size sawtimber.

Undoubtedly, most of the stands in northern forest types have an imbalanced diameter distribution; that is, there are excesses in some diameter classes and deficiencies in others--although graphically resembling the typical reverse-J-shaped form. Also, the average q is probably somewhere between 1.7 and 2.0--somewhat high--and merchantable trees larger than 20 inches dbh are not too prevalent.

Many uneven-age management recommendations suggest diameter distribution or stocking goals based on a

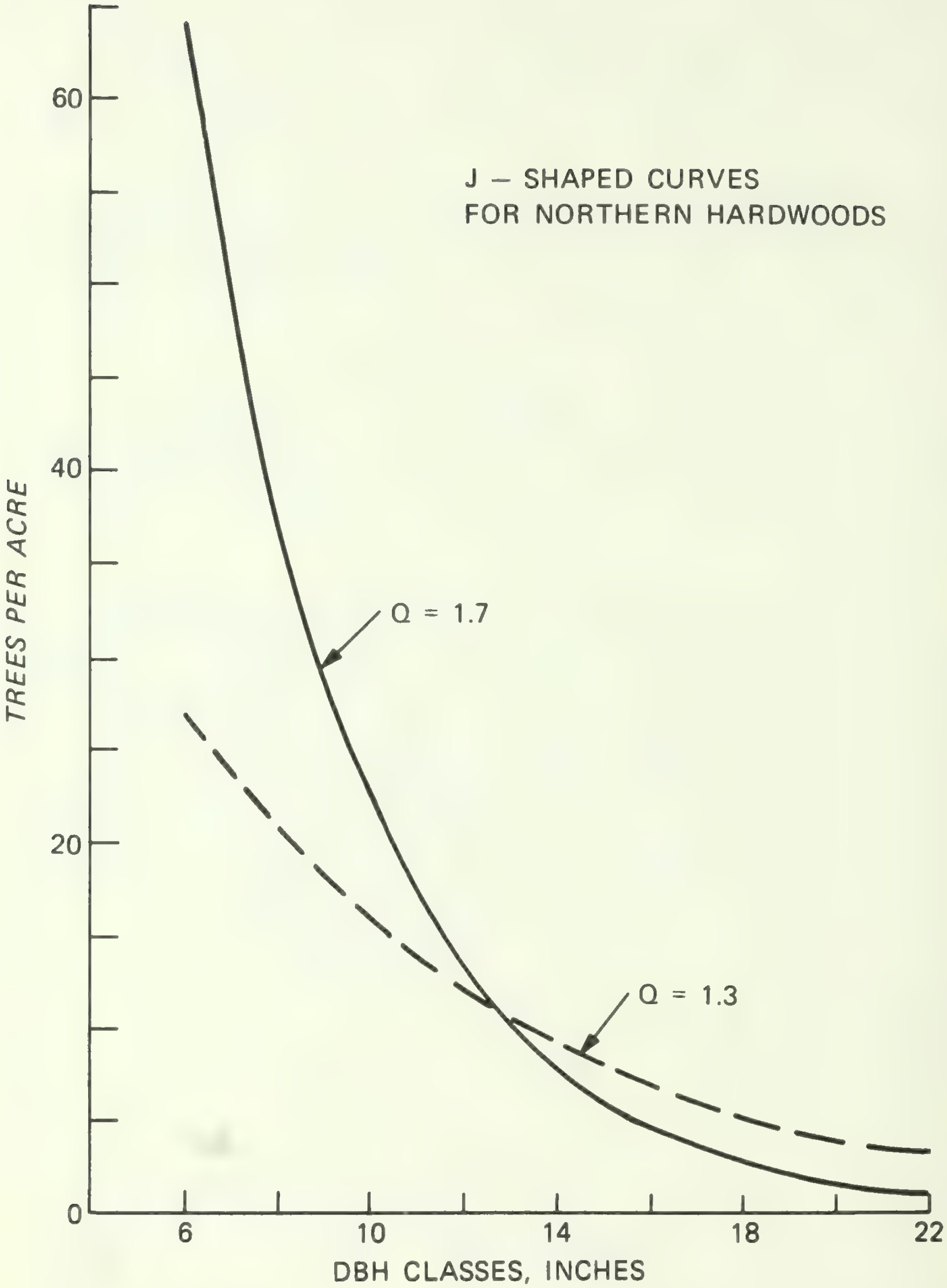

Figure 1.--J-shaped curves for northern hardwoods.

a constant q ratio of 1.3. This probably is too low for most stands, if the major objective is timber production. A q of 1.5 or a little higher would be a more realistic long-term goal. Some stands may require several improvement or conditioning operations before the long-term goal is achieved. In the improvement or conditioning operations, it may be more economical to regulate initial yields by a set of components that blend more closely with existing stand conditions.

For example, for second-growth northern hardwoods in New England, which usually have a high q, we recommend an initial structural guide based on a q of 1.7 or 1.8, about 70 square feet per acre, and a maximum diameter class of 18 or 20 inches (Leak and Filip 1975). If we attempted to use a management package based on a q of 1.3 or 1.4 and 80 square feet per acre, and a 22- or 24-inch maximum tree size as an immediate goal, we would run into application problems. Trees in the large sizes would be lacking, and a heavy treatment in the small sizes would be required--which may not be economically justified. However, these latter components could probably be applied immediately in many old-growth northern hardwood stands.

After a timber cruise is made, q can be calculated for the stand by using the least-squares method proposed by Leak (1963). Armed with the information on q, as well as the desired stocking goal and maximum tree size, a forester can readily compute a stand-structure guide for the tract (table 1). From this computed information, an allowable harvest by diameter classes can be determined.

A more practical procedure, especially in small woodlands, is to use a diagnostic tally sheet containing a stand-structure guide based on a predetermined value of q (table 2). After the timber cruise is made, a forester can visually compare the structure of the stand with structures based on different q values; then he can select the one that compares most favorably. The next step is to prepare a prescription for treating the stand.

When marking the timber, it is often more practical--especially on large units of 100 acres or more--to guide the allowable harvest tally by grouping the trees in broader diameter classes than 2 inches. Three or four diameter groups can be used in the field if necessary, corresponding to poletimber--6, 8, and 10 inches; small sawtimber--12 and 14 inches; medium saw-

Table 1.--Calculation of a stand-structure guide for uneven-age management

1. List the dbh classes to be used. As a trial run, start with one tree in the largest diameter class. Keep multiplying by the selected q to get the number of trees in each smaller diameter class.

2. Calculate the basal area of each dbh class and determine the total basal area.[1] This total basal area will not agree with the desired residual basal area stocking. Therefore, determine the ratio between the desired residual basal area and the calculated basal area.[2] Multiply this ratio or correction factor by the numbers of trees and basal area in each diameter class. This correction gives the desired stand-structure guide.

Dbh class	Trial run (q = 1.7)		Desired structure (q = 1.7)	
	Trees per acre	BA per acre	Trees per acre	BA per acre
	No.	Sq. ft.	No.	Sq. ft.
6	40.8	8.0	63.5	12.5
8	24.0	8.4	37.3	13.1
10	14.1	7.7	21.9	12.0
12	8.3	6.5	12.9	10.0
14	4.9	5.2	7.6	8.1
16	2.9	4.0	4.5	6.2
18	1.7	3.0	2.6	4.7
20	1.0	2.2	1.6	3.4
Total	97.7	45.0	151.9	70.0

[1] BA per dbh class = $0.00545D^2$.

[2] Ratio or correction factor = $\frac{70}{45}$ = 1.556.

TABLE 2.--DIAGNOSTIC TALLY SHEET FOR UNEVEN-AGE MANAGEMENT

Cumulative Tally - Number of Trees Per Acre (B.A. Factor 10)

DBH	Number of Trees														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
6	51	102	153	204	255	306	357	407	458	509	560	611	662	713	764
8	29	57	86	115	143	172	201	229	258	287	315	344	372	401	430
10	18	37	55	73	92	110	128	147	165	183	202	220	233	257	275
12	13	25	38	51	64	76	89	102	115	127	140	153	165	173	191
14	9	19	28	37	47	56	65	75	84	94	103	112			
16	7	14	21	29	36	43	50	57	64	72	79	86	Basal Area		
18	6	11	17	23	28	34	40	45	51	57	62	6	Per Acre (sq.ft.)		
20	5	9	14	18	23	27	32	37	41				Merchantable		
22	4	8	11	15	19	23	27	30	34						
24	3	6	10	13	16	19	22	25	29	Tally Legend	#Prism Points				
26	3	5	8	11	14	16	19	22	24				Cull		
28	2	5	7	9	12	14	16	19	21	/					
30	2	4	6	8	10	12	14	16	18	0					
Total										X	Total B.A. ______ sq.ft.				
											Total #trees ______				

Total Number of Trees Per Acre - Add the last figure used in each block and divide by the number of point samples tallied.

B.A. per acre - Add the total number of entries by class (first row), multiply by 10, and divide by the number of point samples tallied.

STAND DIAGNOSIS

DBH Class	Present Stand		Q = 1.7		Surplus (Deficit)		Marking per acre	
	Trees per acre	Basal Area per acre	Goal per acre		Trees per acre	Basal Area per acre	Trees	B. A.
			Trees	Basal Area				
	No.	Sq. ft.	No.	Sq. ft.	No.	Sq. ft.	No.	Sq.ft.
6			63	13				
8			37	13				
10			22	12				
Sub-total			122	38				
12			13	10				
14			8	8				
Sub-total			21	18				
16			5	6				
18			3	5				
Sub-total			8	11				
20+			1	3				
Sub-total			1	3				
Total			152	70				

(Tally sheet suggested by Ken Lancaster), USDA, Forest Service) timber--16 and 18 inches; and large sawtimber--20 inches plus.

DISCUSSION

I believe a general misunderstanding of how uneven-age management works has caused much reluctance by many foresters and timberland owners to accept the system or to apply it completely. You either cut too much, or not enough, or the wrong trees; that has been the usual response. But as I described the details of the system to you, it can be made to work with flexibility to fit many stand conditions. Also, we now have tree-value conversion standards for several hardwood species, even to the point of making on-the-ground projections of each tree's development, based on each tree's own unique characteristics (DeBald and Mendel 1976; Mendel and others 1976).

Some foresters believe that it is difficult to harvest marked timber, as required by the system over a range of diameter classes, without injuring or damaging much of the residual growing stock. This is true to a degree. Regardless of whether track-type or wheeled skidders are used, some tree injury will occur. The injury need not necessarily exceed acceptable limits for timber production.

In a logging-damage study in northern hardwoods in New York State, logging injured about 30 percent of the residual trees; and major injury was done to about 20 percent (Nyland and Gabriel 1971). In our uneven-age management studies at the Bartlett Experimental Forest, logging injuries have been within these percentage ranges or usually lower. Of course, if felling and skidding operations are not planned properly, injury could be much higher, which would have a serious impact upon future tree quality. We must remember that logging injury can also occur in timber tracts under even-age management, particularly during commercial thinnings. Some care must be exercised under both systems.

Others say that uneven-age management can be applied only on small timberland ownerships--up to 200 or 300 acres. However, there are many portions of larger ownerships where uneven-age management would also be applicable. Areas with fragile soils, or with steep topography, or those areas that have high esthetic appeal, should probably be under uneven-age management. There are other areas covered by northern forest types that should also be considered for uneven-age management, especially where public use is increasing or multiple-use management is important. Where such areas must be partially cut to maintain high-forest conditions, they could be managed for sustained yield under uneven-age management, using the three basic components for stand manipulation that I have outlined.

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EVEN-AGED INTENSIVE MANAGEMENT
TWO CASE HISTORIES

by Harold M. Klaiber, Forestry Manager, Northeast Operations, Scott Paper Company, Winslow, Maine.

INTRODUCTION

In 1967 Scott Paper Company merged with the S. D. Warren Company and S. D. Warren became a division of Scott. In 1969 the S. D. Warren timberlands in the Bingham, Maine area were transferred from the Warren Division to the Northeast Operations of Scott. Included in this transfer were approximately 700 acres of tree plantations which had been established in the 1920's and early 1930's. A wide variety of both native and exotic species were planted. These included Douglas-fir, Norway spruce, European larch, Austrian pine, red and white spruce, and red and white pine.

As case histories to illustrate the practice of even-aged intensive silviculture, I have selected one plantation consisting of native red pine and white spruce in alternating rows, and one plantation of exotic Norway spruce as a pure stand.

TUSCON PLANTATION

The red pine (Pinus resinosa Ait.) and white spruce (Picea glauca Voss) plantation is located in Bingham, Maine and is commonly called the Tuscon plantation. The plantation contains 31 acres, of which 14 acres are alternating rows of red pine and white spruce. The planting site was an old field that had not been mowed and weedy vegetation occupied the site. Planting was done in the fall of 1930 at a cost of $10.40 per acre.

Initial spacing was 6 feet x 6 feet.

The white spruce planting stock was 3-1, and the red pine stock was 2-1.

In 1948 and 1949 the red pine was pruned. The stand was also thinned on an individual stem selection basis. The records do not indicate how much volume was removed, but report a profit of $31 per acre over and above the actual thinning cost, so some merchantable volume must have been removed in the thinning.

In 1971 increment borings on the red pine which had almost completely over-topped the white spruce showed that the red pine grew at a maximum of 5 rings per inch, but by 1971 had slowed to 10 rings per inch.

Also in 1971, measurements on 3 sample plots showed the following:

Species	Volume in Cords/Acre	Basal Area per Acre
Red pine	54.2 Cds.	186 sq. ft.
White spruce	7.3 Cds.	31 sq. ft.
Combined	61.5 Cds.	217 sq. ft.

In the 41 years since planting, merchantable volume growth averaged 1.5 cords per acre per year. This figure does not include the volume removed in the 1948-49 thinning because no record of the actual volume removed is available.

BRAZIER PLANTATION

The Norway spruce (Picea abies (L.) Karst.) plantation that I selected for the second case history is located in Brighton, Maine and is commonly known locally as the Brazier plantation. The total plantation is 27 acres, of which 10 acres are pure Norway spruce. The planting site was an old field with heavy grass cover. Planting was done in the spring of 1921.

Initial spacing was 6 feet x 6 feet.

The planting stock was 2-1.

In 1928 at plantation age 7 years, the Norway spruce were released from alder and grey birch competition which are typical volunteer species on old fields in this location.

In 1941 at plantation age 20 and again in 1948 at plantation age 28, individual crop trees were pruned.

In 1955 at age 34, the plantation contained a volume of 30 cords per acre. A thinning removed every 6th row of trees completely and removed individual stems on a marked tree basis in the 5 residual rows. Approximately 20% of the total merchantable volume was removed leaving a residual volume of 24 cords per acre for the entire 10 acres.

The year following this thinning, in 1956, a permanent 1/4 acre sample plot was established. The results of 20 years of measurements on this plot are shown in Table 1, covering the period from July 2, 1956 to June 30, 1976.

Table 1. BRAZIER PLANTATION - NORWAY SPRUCE

Date	Cords/ Acre	Basal Area (Sq.Ft.)	Avg. DBH (in.)	Avg. Height (ft.)
7/2/56	31.3	133	8.95	46
11/59	36.8	162	9.85	50
12/3/65	43.3	184	11.30	58
6/16/70	52.7	211	12.00	69
11/17/71	55.5	225	12.20	71
9/26/73[a].	44.9	175	10.30	71
6/30/76	48.5	187	10.40	71

---

a. After thinning.

In 1971 the plantation averaged 55.5 cords per acre with an average DBH of 12.2 inches. In early 1972 additional thinning was done with individual trees removed on a marked tree basis. Removal in this thinning averaged 10 cords per acre.

Based on the 1976 remeasurement of the permanent plot, the present stand volume is 48 cords per acre. The two thinnings have removed 15 cords per acre making a total net merchantable growth of 63 cords per acre for the 54 years since planting. This averages 1.2 cords per acre per year for the 54 years.

During the 16 year period between thinnings (1956 to 1971) the net merchantable growth was 24.3 cords per acre or an average of 1.5 cords per acre per year for each of the 16 years.

EVEN-AGED GROWTH POTENTIAL

In both case histories cited, the intensive management consisted only of:

1. Species selection
2. Control of initial spacing
3. Early release from volunteer hardwoods
4. Thinning at infrequent intervals

One can only speculate what the growth potential of even-aged stands would be if initial planting stock were selected for superior growth capabilities, if the stand were fertilized perhaps 2 or 3 times during the rotation, and thinning was done at more frequent intervals. I believe these two case histories demonstrate that with some modest increases in the intensity of our management it is extremely likely that a minimum growth of 1.5 cords per acre per year over the entire rotation could be attained on considerable acreage in Maine.

SILVICULTURAL SYSTEMS - UNEVEN-AGED MANAGEMENT

by Morris R. Wing
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Uneven-aged Management, to me, indicates some form of partial cutting, perhaps selective cutting or diameter limit control in the harvesting cut, which, in most cases, removes the larger diameter, more mature trees and leaves a residual stand composed of healthy, fast-growing, well-spaced second growth timber, with a good number of trees in the 6" - 12" diameter class.

My whole forestry background has been largely oriented towards some form of partial cutting, having been brought up in a logging family that believed strongly in this method of handling timberland. In fact, my own experience, gained from over 40 years of working with and observing the forests of Maine, has done nothing to shake my original belief that some form of selective or partial cutting is best suited for a high percentage of Maine forest land and, most particularly, for the spruce-fir type. Natural regeneration and good stocking is no problem here and nature needs only a little help to improve growth rates markedly.

I can think of only two future changes that could greatly alter my thoughts along these lines. One would be the development of some fast-growing softwood species or "super tree" that could be, hopefully, planted cheaply and would grow several times faster than natural regeneration. The other break-through would be some method wherein pulp mills could utilize bark-on softwood chips that would permit commercial and profitable thinnings of softwood thickets that normally occur after clear-cutting procedures.

When thinking of partial cutting, there comes quickly to mind several distinctive benefits to the landowner:

1. Better and more continuous growth rate (no raspberry stage).
2. Less exposure to a disastrous fire.
3. Better conservation of both soil and water.
4. Better control of desirable species mix in the residual stand and the natural regeneration that follows harvesting.
5. The control of species mix helps to reduce susceptibility to future insect epidemics; i.e., spruce budworm.
6. Improved wildlife habitat (for the public).
7. Higher return per acre because of increased stumpage values from sawlog quality, larger diameter trees.
8. Maintaining a constantly high resale value of the land, due to the ever-presence of a residual merchantable stand.
9. More frequent and continuing stumpage returns, with the escalation of stumpage value staying closer to the ever-increasing expenses of supervision and logging.

I did not mention in the above listed advantages the subject of aesthetics, but, surely, this is uppermost in the minds of some, and cannot be wholly discounted.

It is my strong belief, in view of rapidly rising cost of supervision and land taxes, that a forest landowner in Maine can no longer afford clear-cutting, in most instances. In this land of long, cold winters, the landowner cannot lose a single growing season. It is true that the landowner may gain in lower logging costs at the time of cut, but the continuing annual expenses of administration, protection, and taxes will

will surely eat up the money saved in logging expense before he can return to cut again on the same parcel.

It is apparent that it is becoming increasingly difficult to perform selective cutting in large commercial operations. It is also true that most mechanical logging systems on the market today do not lend themselves well to a system of partial cutting. It is my belief, however, that just around the corner, in Maine, there will be a need for more intensive forestry and, with this approach, the demand for machines oriented toward partial cutting will manifest itself. Heretofore, in Maine, wood supply has not been a problem and the demand has been for a machine to (1) replace labor, and (2) to log more cheaply, although it is sad to contemplate that this has not been achieved. It is obvious that the timberland base is going to remain about the same in this State and, somehow, more intensive forestry must be practiced if the growth rate is going to meet the demand.

Twenty years ago this spring, in 1956, International Paper Co. commenced the first large-scale marked wood operations in Maine. I think it will make more sense to you if I confine my remarks to spruce-fir management in northern Maine and I would like to use Twp. 16 Range 9 as an example of what one might expect as a result after some 50 years of partial cutting. I chose this town particularly because the cutting history of this land is typical of many land ownerships in northern Maine. T 16 R 9 is located fairly close to the confluence of the Allagash and St. John Rivers, with the township draining northerly into the St. John and easterly into Fish River. Company ownership in this town commenced by purchasing 1/4 interest in common and undivided in 1917. Over the years, the Company has acquired additional interest in this town until the present ownership is 65/72 I-P and 7/72 Pingree Heirs. This is a full size township comprising 23,340 acres, with almost exactly 80% of the land area in either mixedwood or softwood type. Although there are small volumes of white spruce and black spruce in the softwood mix, the major species, by far, consist of red spruce and balsam fir. In our Maine lingo, Foresters would refer to T 16 R 9 as a "good growing town", meaning a good site, well drained, and definitely better growth than experienced on some other towns.

I think I should start the story on this town with a Company cruise in 1927 as made by John Marsh under the direction of Charles King. This cruise was made immediately after sawlog operations were completed, with most timber being cut to a stump diameter of about 12". This 1927 cruise found a residual stand of 144,000 cords, or 6.2 cords per acre. Some comments in this 1927 cruise report may be of interest to you.

The cruiser referred to two small sawmills that had been operating on the town during the 1920's and both of these mills had machinery for making shingles as well as lumber. He also commented that the sawlogs were hauled to the mills by log haulers and that the town had been cut hard (in his opinion) during the last 15 years.

I believe the significant thing here is that there was a residual stand left of some 6.2 cords of spruce-fir per acre, with 56% of the softwood volume in trees 10" d.b.h. and larger.

For the next 20 years, through the depression era, there was very little cutting of any kind taking place on this ownership and the next inventory figures available on this town were developed from a joint cruise by Great Northern Paper Co. and International Paper Co. in 1946. This cruise indicated a total stand of 213,000 cords, with an average stand per acre of 8.88 cords of spruce-fir. A few comments made in this cruise report might also be of interest.

I note that the cruiser is still making observations in 1946 about a road system that needs corduroying. He also mentioned extensive damage to white and yellow birch by the bronze birch borer. He also stated that in spite of heavy logging prior to 1929, "there is a good stand of spruce-fir on this town, due no doubt, to the fact that at the time of operating, the smaller diameter trees were not considered merchantable". The cruiser found no evidence of epidemic infestation of insects; so apparently this town missed the earlier spruce budworm epidemic.

Shortly after this cruise and in 1949, we commenced extensive operations on this town, with 179,000 cords being removed during the next 12 cutting seasons through 1960. All of these operations were on some type of a partial cutting basis, with the period 1949 through 1955 on diameter limit controls, and with the period 1956 through 1960, for the most part, marked wood on an individual tree selection basis. Since 1960, little cutting took place on the town until the spring of 1975 when nearly 5,000 cords were salvaged as a result of the spruce budworm epidemic. The total volume removed from the town, 1947 through 1975, and before the 1975 cruise, was 185,000 cords.

This township was re-cruised again last year (1975) which is some 15 years after large-scale operations ceased. The 1975 cruise revealed a total stand of 226,000 cords of spruce-fir, with 51% of the volume in sawlog quality trees 10" d.b.h. and larger. I might mention that the 1975 cruise indicated a stand of 11 cords per acre in the softwood plus mixedwood types and 13.6 cords per acre in the softwood type only which comprised almost exactly 50% of the total forested area. Of this volume above 10" d.b.h., 55% is spruce and 45% is fir.

Now, bear in mind that this present stand of timber on T 16 R 9, comprising 13.6 cords per acre in the softwood type, is now ready to cut again, even though 185,000 cords of softwood were removed from this town between 1949 and 1975. A comparison of the 1927 cruise with the 1975 cruise indicates that land classified as softwood had increased from 38% of the area to 49.8% of the forested area. It is true that some of this difference could be caused by a variation in cruising techniques, but it is obvious that the partial cutting procedures had at least maintained, and probably increased substantially, the acreage in softwood type.

There are many ways of expressing growth and growth rates on forest land. However, a factual examination of the growth data on this town between 1946 and 1975, based on actual cords removed and cords now standing in 1975, indicates a growth rate of .353 cords of spruce-fir per acre per year on the mixedwood plus softwood types together (18,327 acres).

Of course, if the rate of growth could be identified separately on just the softwood type, it would be considerably more than the .353 cords per acre aforementioned.

I would like to have you bear in mind that the results on this town were obtained with no added expense of site preparation, planting, or the incumbent costs associated with artificial regeneration. The only extra costs involved here were some 22¢ to 30¢ per cord for tree marking spent on approximately one-half of the volume that was removed. The cutting operations were on a large-scale, commercial basis, with the cutters all paid on piecework. The operations were nearly 100% horse yarded. During the cutting operations, we were blessed here with a Woods Superintendent who had an intense desire to see the land handled well, two cooperative woods contractors, and two thoroughly experienced Scaler-Inspectors. Pulpwood from this town is expensive, at a long freight rate, and our new mill at Jay had not yet been built at the time of these operations. In fact, at that time, we were hard pressed to market the allowable cut. However, it is my belief that if conditions had permitted the expenditure of a few dollars more per acre to further improve and control the harvesting, we could have increased the growth rate per acre on the residual stand even more than has been experienced.

Time has permitted me only to sketch briefly the history on this one township in northern Maine, which is surely not the worst land owned by International Paper. I believe you can agree, from the facts presented, that with only a little care exercised in the harvesting, you can "have your cake and eat it too" in the spruce-fir type of northern Maine.

NATURAL REGENERATION - SMALL OWNERSHIPS FROM CONCEPT TO PRACTICE

by Arthur G. Dodge, Jr., North Country Resources Conservation and Development Area Forester, New Hampshire Cooperative Extension Service, Conway, N. H.

Abstract

Established concepts of successful natural regeneration are not necessarily practiced on small ownerships of ten to 500 acres. Unevenage management will be the primary management system on small ownerships and natural regeneration is the most practical method of providing for continuous forest production. We can obtain satisfactory natural regeneration by good planning and proper supervision of the on site application of necessary techniques.

Small Ownerships

American Forest Institute tells us that individuals own 59 percent of the commercial forest land in this country. This is a significant portion of our forest and small ownerships fall within this category. For the purposes of this paper, I will be discussing ownerships of 10 to 500 acres in size (4.05 - 202.40 hectares). In the three southern New England states plus New Hampshire and Vermont, the USFS Northeast Forest Experiment Station estimates that there are some 348,000 private landowners. Of this group, approximately 150,000 (43 percent) own more than ten acres but less that 500. In New Hampshire, the average privately owned woodlot is about 47 acres and I believe the average within the northern forest types that we're discussing probably will not be much larger than that, but for today, let us consider ownerships up to 500 acres.

There are several premises upon which I base this paper. They are:

A. These owners will continue to depend on natural regeneration to reproduce trees on their woodlots.

B. With the exception of a few pure stands of white pine and spruce-fir, management on these areas will be primarily unevenaged. Well over half of New Hampshire's commercial forest is in mixed hardwood-softwood types or hardwood types. I am assuming that this is pretty much

> the case for the rest of the area that concerns us. Unevenage management seems more practical on small ownerships containing these types. Another reason that I believe unevenaged management will prevail is that even though the reconstituted wood industry has grown at approximately 15 percent annually over the past few years, the price for fiber alone will not be attractive to this owner. Mr. Charles W. Bingham of Weyerhaeuser Company expressed this idea very well when he spoke to the Sixth American Forest Congress at Washington, DC in October 1975. He stated that "The industry is also a direct user of its own raw materials, to a large degree. Through its manufacturing facilities, it can obtain efficiencies and values that the owner of a 40-acre woodlot cannot achieve." According to Nick Engalichev, our Extension Utilization and Marketing Specialist at Durham, wood in the solid form is going to get more value recognition. To quote him, "Good hardwoods are going to be worth the price of gold." He tells me that on today's wholesale market, a thousand board feet of the top grades of northeastern oak sells in the 500 dollar range.

The other factor that requires us to think in terms of unevenaged management is, this landowner usually wants to use his or her land for several purposes. Timber production is not necessarily the main aim in life and the owner is unwilling to have large areas clearcut at any one time. A large area in this owner's mind may be two or three acres. Ten acres could be "complete devastation".

I would also like to point out that my statements regarding natural regeneration are based on some application of other people's research, and personal observation of small ownership forest management in the New England area since 1957.

Natural Regeneration Concept

Before we talk about natural regeneration practices on the small ownership, we should consider several related ideas or concepts. First, assuming that a preferred species seed source exists in the area, there will nearly always be some natural regeneration. This regeneration really has no expense attached to it. You might say it's pretty much a gift of nature. Secondly, the sixth edition of "The Practice of Silviculture" by Hawley and Smith states "Most of the answers to problems of securing natural regeneration are to be found in existing forests". In my experience I have found this to be very true. The third concept is that a tremendous amount of written information on this subject exists. The Northeast Forest Experiment Station publications, various university bulletins, textbooks, and Forest Service handbooks are all available and should be included in your personal, company or institutional libraries.

Practice

In practice I have found several things of interest and very apparent on the small ownerships that I have observed:

A. The desirable natural regeneration has occurred pretty much by chance and is usually associated with a silvicultural activity. In most cases, this has been an unsupervised harvesting operation.

B. Much of the regeneration is not where we want it. It's found primarily in or adjacent to logging roads or yards that will have to be relocated in the future if we decide to produce timber from this regeneration. If the young trees are not growing under the previous situation, they will be found in close proximity with or, what I term, within easy suppression distance of unwanted species.

C. In the case of intolerant and intermediate species you may, at first glance, get the impression that natural regeneration has not provided enough desirable specie stems per acre.

Even though these are the conditions that usually exist in practice, I see no reason why we cannot provide plentiful natural regeneration of the species we choose. In my opinion this is the only way to go when dealing with small ownerships. Stand establishment by direct seeding is a more expensive alternative. At this point in time, it appears that conventional planting is just too expensive. Good planning, layout, and particularly supervision, are the criteria for successful natural regeneration. We must keep in mind such things as seed source, timing, amount of shade or sunlight necessary, site factors, plus forest protection and be sure that the proper techniques are accomplished on site.

The biggest problem is getting to the landowners and convincing them that intensive culture is needed. I remind you that in two recent forest landowner studies the USFS Northeast Forest Experiment Station indicates that no more than five percent of small ownerships receive professional advice during harvest operations. I understand this includes selection or intermediate cuttings. I've long been of the opinion that our profession has not been in the driver's seat, particularly when it comes to the management of small forest ownerships. National commercial forest production statistics bear this out. We foresters have to go on the offensive, convince these landowners that we know how to make their lands more productive, and that there is not just one step but many steps in maintaining this renewable resource. Establishing a forest by natural regeneration is the least expensive and most practical first step in the cycle.

PUBLIC LANDS - FROM CONCEPT TO PRACTICE

by: John J. Vrablec, District Ranger, Evans Notch Ranger District, White Mountain National Forest, Bethel, Maine

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Abstract

Intensive timber management can and is practiced on National Forest lands in the Northeast. There are, however many constraints and limitations which are placed upon the public lands manager. The key issue here is that the National Forests are PUBLIC lands which must be managed for the public.

INTRODUCTION

So far today we have heard much about what is available or ideally desireable in the science of intensive forest management of Northern Forest Types. I have been asked to comment as to how these concepts are practiced on public lands in a sort of case history. My approach will be simply to relate in a very nontechnical manner the experiences of a public land manager on one of our National Forests.

BACKGROUND

Many of you are aware of the many laws and regulations under which the National Forests are managed. I will name only a few of the key ones which do have and will probably continue to have direct impact upon the practice of intensive culture of any forest types. They are:

1. The Organic Administration Act of 1897 - provided for management, protection and use of the Forest preserves.
2. The Multiple Use - Sustained Yield Act of 1960
3. The Wilderness Act of 1964
4. The National Environmental Policy Act of 1969
5. The Forest and Rangeland Renewable Resources Planning Act of 1974 (RPA)

There is also new Legislation pending which many of you are aware of. Such bills as Senate Bill 3091 (Humphrey Bill) and its companion bill H.R. 12503 + 13832, Senate Bill 2926 (Randolph Bill) and its companion bill H.R. 11894 and Senate Bill 2851 are some of the bills, which would have an impact on how, if any, forest management will be practiced on National Forest lands.

The White Mountain National Forest made a management plan modification in 1968, which changed the system of timber management from uneven - aged to even - aged. This was based on results of research conducted at the Bartlett Experiment Forest over a 30-year period which indicated that even-aged management of northern hardwoods and associated species was a desireable system. Thus, the present timber management and therefore any intensive culture of Northern Forest Types on the WMNF is based on this even-aged system.

PRACTICE

The general objective of timber management on the WMNF will be to grow and harvest timber crops to the best public advantage in accordance with the previously mentioned laws and regulations. A timber management plan provides guidance for the development of the timber resource.

Some Specific Objectives Are:

1. Development of even distribution of age classes by the end of 1½ rotations.
2. Increase the proportion of desireable species (yellow birch, paper birch, white ash, sugar maple and red spruce) through proper cutting methods and timber stand improvement work.
3. Market the full potential yield consistant with Multiple Use requirements.
4. Maintain a healthy, vigorous forest.

To achieve the stated objectives, coordination of all the land and social resources of the National Forest are needed. This coordination is achieved best through the Land Use Planning practices and policies which are carried out on the WMNF as well as throughout the Forest Service. Here on the WMNF, we have completed the "Guide for Managing the National Forest in New England" in 1973 and the "Forest Plan - WMNF" in 1974. These planning documents provide the guide and policies for all coordination requirements between timber management activities and other resources. The third step in this planning effort, the individual Unit Plans provide even more specifically the necessary coordination as it applies to individual areas on the Forest.

I will not go into great detail as to the specifics of the management guides for the various timber types on the WMNF since that would entail a detailed description of the Timber Management plan itself. Some over-all guides and comments are as follows:

1. The Spruce-fir type which comprises 11% of the commercial forest land on the National Forest, is managed in accordance with "A Silvicultural Guide for Spruce-Fir in the Northeast" USDA report NE-6. Rotation age will be 90 years

for red spruce. Balsam fir should be removed as part of an intermediate cut before age 70. Regeneration can be either shelter wood or final harvest.

2. The Spruce-hardwood type which comprises 24% of the CFL on the National Forest has a rotation age of 110 years. Regeneration cutting will be by the shelterwood method. Balsam fir should be removed during intermediate cuts (thinnings) prior to age 70.
3. The Maple - Beech - Birch type, which makes up the majority of the CFL (58%) will be managed using "A Silvicultural Guide for Northern Hardwoods in The Northeast" USDA Research Paper NE - 143. The rotation age will be 120 years. Regeneration cutting will generally be by Final Harvest (patch, strip or stand) and seed tree methods.
4. The Paper Birch type, although a small component (7%) of the CFL, is economically important. The management guide used is "A Silvicultural Guide for Paper Birch in the Northeast" USDA Research Paper NE - 130. Rotation age will be 70 years. Regeneration will be by final harvest and seed tree cutting methods where more than 50% of the future stand will be paper birch.

These guidelines are just a few of the many that the professional forester has to guide him in the scientific application of forest management on the WMNF. There are many more, quite specific as to area (acreage) control, potential yield, allowable cut, etc. All of these speak to the professional forester and to his scientific management. But what about the human side of the coin or the fact that the National Forests are public lands?

CONFLICTS/OPPORTUNITIES

Again, as you probably are all aware of, National Forest management must be responsive to the myriad of laws, national interests, public demands for the various uses of the National Forest, and a land use ethic which at times defies purely scientific or technological knowledge.

Since converting to the even-aged system on the WMNF in 1968, we also have had to cope with the many multiple-use conflicts and opportunities which have risen. For instance, during the period of 1971 to 1975, we had harvested 528 acres of softwood stands and 8654 acres of hardwood stands through intermediate cutting practices, and 543 acres of softwood stands and 6173 acres of hardwood stands through regeneration cuttings. And even though we had some rough moments, we do continue to be able to practice the types of harvesting methods which have come under fire in other parts of the country.

Because of its location, the WMNF is one of the most highly used National Forests in the country. Recreation use and management permeates every facet of our operations. We have many user publics, ranging from the ultra-preservation minded to the exploiter, the sightseer to the logger, the hunter to the bird watcher.

AVOIDING THE CONFLICT

How do we deal with all these conflicts and opportunities? I wouched very briefly upon our Land Use Planning process and won't go into any details because I believe there will be another speaker dealing with the subject. I do believe however, that we have dealt with these issues in at least two parallel means which have contributed to our staying out of court, so far. These have been through our Information and Education processes (keeping the public well informed) and through our own policies of public involvement in our decision making processes.

To expand a little on these, we have made every attempt at informing the general public, the pressure groups, and the individual of every facet of our management practices. No longer can any one of us assume that the public is disinterested or ignorant of what we are attempting to do. We therefore concentrate, through the educational process, on having a knowledgeable public work with us in resolving the issues and conflicts.

This leads us into our second most valuable tool, Public Involvement. To state it very briefly and non-scientifically, we ask the public how they would like to see us manage their lands. Of course we don't do this blindly. We attempt to present the public with all of the facts, scientific knowledge, technical data, etc. that we have gathered. This is done by the professional on the ground. He also uses his scientific knowledge and training to recommend what he believes in the best course of action. This then is sent out to the various publics with the request that they study it and give us their input. We stress very strongly that they not only tell us what they do or don't like, but more important, that they provide us with their rationale for their recommendations. By analyzing the inputs from the public and combining it with our analysis, we have been able to come up with decisions for forest management which at least to date has worked fairly well.

Over the years we have developed a sensitivity to some of the conflicts which impact forest management practices on public lands. We have for instance limited our individual clearcutting Units to 40 acres and in some places even down to 10 acres. We recognized that aesthetics played a major role in how the majority of the public viewed our management practices. These same practices have been modified by our wildlife considerations.

I could go on and on about the various considerations interwoven into our land management. It should be clear that the key word or issue here is that we deal with "Public" lands, in which the public has a vested interest and in which the public is apparently demanding its say.

ARTIFICIAL REGENERATION; APPLICABILITY, OPTIONS AND RESEARCH NEEDS

by

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Abstract

In this overview of the status of reforestation in the northeastern United States, the applicability of natural regeneration is compared to planting and direct seeding. Foresters are urged to conduct careful planning of reforestation and to use harvesting as a silvicultural tool. Landowners are cautioned against the use of clearcutting unless they are prepared to use artificial regeneration measures. Research in the economics of reforestation options is recommended and the importance of forest genetics research to the regeneration phase of intensive forest management is emphasized.

One of the major decisions to be made in the sustained yield management of any plant crop is how to first establish it and then how to replace it after harvesting. Most so-called "cultivated plants" require much human assistance, not only in their establishment, but in subsequent survival, maintenance of genetic identity and continuance in usefulness to mankind. Only a few species of cultivated plants provide the world population with the bulk of its food. They have little resemblance to their wild ancestors and are biological monuments to man's long-term efforts in selection, introduction, breeding and intensive management.

Conversely, tree species yielding most of our world's wood products are essentially "wild plants" and persist as a residua of man's exploitation. The northern forest types of concern to this symposium contain no exceptions. They consist almost entirely of indigenous species which have attracted little attention to improve or even preserve their existing genotypes and they have not been intensively managed except experimentally or on a small scale.

NATURAL REGENERATION

Although the records show that nearly two million acres have been planted to trees in New England and New York, most of this has been done on abandoned farmland and forest landowners in the Northeast have concerned themselves but little with artificial regeneration as an alternative available to them in re-establishing forest types following logging. Trees eventually replace trees and most resulting species have been marketable. Thus we have relied upon the resilience of the land to return to us, through succession, a new crop for an old one. Nature, in serving its purpose, has generally satisfied ours for we have not been sensitive to setting standards of composition and stocking which were very demanding of either of us.

Although natural regeneration, when unplanned and unaided, is highly erratic and unreliable as to timing, species, density and distribution, regionwise it has provided a surplus of wood and only following forest catastrophies has our confidence in it been badly shaken. Therefore, it is understandable why people have not pressed for a departure from the traditional dependence upon wild seeds, sprouts and suckers to renew a wild crop.

These are generalities, and are not meant to imply that management of all our woodlands are without purpose, planning or provision for replacement. To the contrary, much progress has been made during our professional lifetimes in promoting those forest practices which at least tend to preserve the status quo of most of our northern forest types. Improved forest protection, more and better access roads, conservative cutting practices, professional custodianship, free consulting services to small landowners and productive research are among the achievements which have helped to move us from the purely exploitative operations of the past toward a more intensive form of socially-oriented forest management. But our achievements have been too few and we should consider our progress with professional discontent, especially from the silvicultural viewpoint. A critical analysis of the status of our regional silviculture would pointedly indicate courses of action and choices of options not necessarily new nor novel but more publicly popular and more privately profitable than those now being followed. No analysis should be necessary to convince us that we should abandon our dependence upon unaided natural regeneration before we are forced into doing so by legislation, as has been the case in several western states.

Choosing the proper silvicultural method of natural regeneration and applying it as intensively as needed should probably be the first reforestation option of many landowners. With most of our major species, ecological knowledge and silvicultural experience are adequate to the task. In those instances where they are not, research to correct such deficiencies should be conducted. However, if man-aided natural regeneration is to satisfactorily serve our purposes, we must adopt a new philosophy toward silviculture and harvesting. They cannot be treated as separate activities as they generally are today. Continuance of the practice of permitting "logging" to primarily serve as a means of removing forest products to keep paper mills and lumber producing plants in operation should not be condoned. Logging must become a management technique and a silvicultural tool or the harvesting will continue only as managed exploitation; and forest re-establishment will be little influenced by silvicultural options of natural regeneration methods. Artificial regeneration will then be mandatory to replace preferred species at proper densities without undue delay.

Natural regeneration methods have the reputation of being less expensive than planting or seeding but they are never free and may not be the cheapest. If we use them, then we should not only carefully evaluate their successes but also compute their costs in order to make proper choices between them and to compare their application with other alternatives. Examples of such comparisons with species of other regions have appeared in recent literature. McDonald (1976) has discussed costs associated with the seed-tree method in regenerating ponderosa pine (Pinus ponderosa) in California. He challenges the belief that this method, which is especially appealing to small landowners, is necessarily cheaper than planting because of such factors as: (1) direct costs resulting from the inhibiting effects of the seed trees; (2) negative effect of advance growth on seedling survival; (3) decrease in stocking and density of regeneration caused by seed tree removal; and (4) increase in logging costs.

Loblolly pine (Pinus taeda) the most intensively planted species in North America, is also successfully regenerated by the seed-tree and shelterwood methods. The decision, therefore, as to the proper method to use is an economic one and Sundry and Lowry (1975) have presented some interesting case studies relating to this decision-making. Important factors influencing the cost of the two natural methods and not tree planting were those associated with: (1) delay in regeneration; (2) tree marking; (3) seed tree (opportunity costs); and (4) pre-commercial thinnings. Costs attributed to delayed regeneration were particularly important to the choice of method, even at relatively low interest rates.

These references are cited to emphasize that the use of any reforestation method should represent a compromise between biological success and economic feasibility. Regardless of the method used, whether natural or artificial, its costs should be determined and compared against other methods and against the probability of incurring a greater cost in the future if no regeneration is planned.

ARTIFICIAL REGENERATION

Planting of Nursery Stock:

The Northeast played a leading role in the early history of reforestation in the United States. The Massachusetts State Nursery at Amherst, established in 1907 (operations terminated in 1970), was one of the first American sources of forest planting stock. Also the state nurseries in New York were once among the nation's leaders in seedling production and innovative techniques of nursery culture.

Low land values, large acreages of abandoned farmland, cheap labor and substantial subsidies helped create a custom, sustain a cause and develop a culture for which there now seems to be little regional demand. The Soil Bank Program of the 1950's stimulated planting but there have been no subsequent instances of motivating circumstances, except for Christmas tree propagation, sufficiently adequate to offset the lack of easy planting sites (those not needing site preparation), increased land values, expensive seedlings and high planting costs. Consequently, the average annual acreage planted in New England and New York has been only about 6,000 and 13,000 respectively, for the past decade and has not increased significantly during the last five years (Table 1). Thus, planting of bare-rooted stock has been largely confined to restocking old fields and pasturelands and is a low-priority option of forest landowners. It is rarely used as an alternative to natural regeneration in revegetating cutover woodlands and its contribution to intensive forest management in the region is inconsequential. It is interesting to note that this situation exists even when three of our prominent northern species (*Pinus strobus*, *P. resinosa*, *Picea glauca*) and two European ones which thrive here (*P. sylvestris* and *Picea abies*)constitute five of the top ten species planted in eastern United States.

Table 1. --Acreage of Forest Planting in New England and New York, 1966-1975 (U.S. Forest Service 1961-75)

State	Acres Planted 1966-75	Avg. Annual Acreage Planted (rounded) 1966-75	1971-75
Connecticut	16,302	1,630	1,950
Maine	20,439	2,040	2,030
Massachusetts	6,302	630	440
New Hampshire	8,657	870	1,030
Rhode Island	2,767	280	290
Vermont	7,133	710	670
	61,600	6,160	6,410
New York	128,262	12,800	13,780

Direct Seeding:

There is also a noteworthy record of this region's involvement in direct seeding. Extensive sowing of pitch pine seed on Cape Cod during the mid-1800's was undoubtedly the first operational direct seeding in this country. Research in contemporary seeding has been conducted by several investigators, beginning in the late 1950's, and in 1964 knowledge gained to that date was presented at a symposium on Direct Seeding in the Northeast. Since then, workshops have been conducted, seeding machines developed and papers published on additional research.

Thus, it has been demonstrated here and elsewhere that direct seeding of some northern species can be successful and could be included among our options of regeneration methods. However, in a recent state-of-the-art paper (Abbott, 1973) it was pointed out that direct seeding was of no practical importance to forestry in northeastern U. S. because it wasn't being used. Only 1162 acres were seeded from 1961-71, a period during which 2.5 million acres of direct seeding accounted for 14% of the land area reforested in the U. S. (Table 2). The regional situation remains unchanged, for less than 100 acres have been sown each year since then.

Table 2. --Contribution of Direct Seeding to Reforestation in the U. S., 1961-1975 (U. S. Forest Service, 1961-75)

Year	Total acres (M) reforested	Number acres (M) direct-seeded	Percent of area reforested by direct seeding
1975	1,930.4	131.5	6.8
1974	1,603.5	166.7	10.4
1973	1,749.7	200.8	11.5
1972	1,680.2	224.5	13.3
1971	1,692.9	242.9	14.3
1970	1,599.8	263.5	16.4
1969	1,457.5	224.6	15.4
1968	1,468.6	218.0	14.8
1967	1,407.7	182.0	12.9
1966	1,319.8	178.8	13.5
1965	1,325.0	188.8	14.2
1964	1,353.6	184.0	13.5
1963	1,362.7	221.5	16.2
1962	1,402.1	210.9	15.0
1961	1,796.2	181.4	10.1
	23,149.7	3,019.9	13.2

Although several factors have contributed to a national decline in the area seeded (Table 2), direct seeding continues to be very important in several states. There are those who believe that it has not been given a fair chance to prove its worth, even in the South, where it has worked well. The major reason why it is not used more by southern foresters has been recently attributed to their reluctance to recommend it. They don't use it because they lack knowledge and experience of how to do so. They object to its use chiefly because they feel it is too technical (Kerr, 1975).

The disadvantages of seeding are well-known, but they are sufficiently over-shadowed by its advantages to earn it a place among our reforestation options in the Northeast. It is the fastest, cheapest, and least labor-intensive of our artificial regeneration practices. It seems unreasonable not to give it an opportunity to serve us simply because we don't know how to use it properly, are unwilling to gain experience with it, or consider it too technical.

Although it is especially adaptable to small woodlots, the principal use of direct seeding in the South and West has been on large, contiguous areas and it is especially applicable to reseeding newly harvested lands as a supplement to or substitute for natural regeneration. It would appear, therefore, that direct seeding has the potential to become very useful to us if we were more receptive to it.

Planting of Container-grown Seedlings:

The third and newest mode of artificial regeneration available today consists of planting small seedlings grown in individual containers in a greenhouse. Given several names in the past under the general title of Container Planting, it is perhaps most precise to refer to this method as "planting of container-grown seedlings" since these trees may be set out in the field either in their containers or without them.

Largely ignored by foresters in the U. S. until after several years of operational use in Canada, planting of container-grown stock has become popular in the Pacific Northwest where it is estimated that over 90% of such stock is being grown. Production has increased from less than a million plants in 1970 to nearly 50 million or 20% of that region's planting stock in 1976 (Ter Bush, 1975).

A North American Containerized Tree Seedling Symposium was held in 1974. Its proceedings and other forestry literature contain many reports on this subject, and an excellent article in the Journal of Forestry (Stein et al.1975) presented an outlook for using this method and described the state of its art.

There are numerous reasons why planting container-grown seedlings is attractive, even though it is likely to be the most costly. Southern foresters are interested in it primarily for the purpose of extending their planting season. Some tree species are difficult to raise in nurseries and are more easily grown in containers in the greenhouse. There is hope for better survival and growth over bare-root stock and greater production and planting efficiency are promised.

It seems more than coincidental, however, that in the region where container seedling production has thrived, forest management is being intensified and increases in reforestation are motivated, at least in part, by laws requiring it. Also, foresters in Washington and Oregon, the two leading states in total acres of direct seeding, have been forced, involuntarily, to curtail this practice because of restrictions on the use of chemical seed protectants and pre-baiting poisons used to reduce small-mammal populations.

Greenhouse facilities permit the growing of seedlings on more flexible schedules, can be constructed quickly and economically and require only about 5% as much area as do conventional tree nurseries. These are important features where good nursery sites are scarce and new planting programs are planned. These features can make the container seedling method particularly appealing to industrial foresters of the Northeast whose companies are interested in intensifying their forest management. Two such companies in Maine have recently become involved in container seedling propagation.

RECOMMENDATIONS

Natural Regeneration:

The biggest step forward, regeneration-wise, toward more intensive forest management in the Northeast would be to take the necessary action to assure that no harvesting is conducted without sound plans for obtaining prompt replacement with a well-stocked crop of commercial species. If landowners do not volunteer this action or are not soon educated to do so, they will eventually be legislated into it. In this respect, the long-range good of society must take precedence over the short-range objectives of property owners. If foresters fail to adopt this philosophy toward our forest resources, then they will generate new restrictions on their options of operations and they will bring about the relinquishment of land-use leadership to others more willing to do so.

With the exception of clearcutting of large areas, methods of natural regeneration, if properly applied, should result in satisfactory crop replacement when mature stands of preferred species are timely cut. However, pre-harvest cuttings, site preparation work and even supplemental seeding may be needed to insure prompt establishment of the new stand.

Although the clearcutting method may not only give acceptable, but also the best results of all our options when applied on small areas of proper configuration, we should be cautious in its use. Criticism and punitive action by the public against this method, whether justified or not, can eclipse the benefits gained from it and eventually delete it from our directory of options or place even more inhibiting restraints upon our management practices. Geographical location, personal preference, nor professional dogma cannot for long isolate us from the opinions of an increasingly critical public. Clearcut harvesting, as distinct from the clearcutting method of regeneration should not be allowed and we could enhance our professional image, create more forestry jobs and promote intensive forest management if we were the initiators of regulations to prevent it.

Future Role of Artificial Regeneration:

Therefore, what is the future role here of artificial regeneration? Will it become an integral part of intensive management of northern forest types?

We probably will continue for more than a decade to use it only sparingly throughout the region, except for such crops as Christmas trees and the unique involvement by a few of the more progressive industrial landowners. This situation will continue as long as: (1) no legal obligations force a change; (2) primary wood processors continue to enjoy a large land base from which to harvest wild crops; (3) there is a surplus of available wood; (4) no forest catastrophies occur; and (5) landowners, particularly forest industry, are not presented with some special circumstance of monetary motivation to intensify their management. The last three of these criteria are particularly vulnerable to change, at least in some areas and with certain species and types.

A need for doubling the nation's wood production in 20 years has been predicted and if this transpires, then the scarcity of supply and escalation of prices of preferred species will force cultural changes.

As a professor of forest protection, I must make a pitch for those practices which are the only reasonable cure for correcting such excessive losses of forest crops as those caused by windstorms, wildfires and epidemics of insects. The first two are always a threat, the third is a reality and all are interrelated. It took forty years to reforest the Tillamook Burn in Oregon, even with the aid of artificial regeneration. We certainly cannot tolerate such a reforestation timetable of any comparable catastrophe in the Northeast, and we should be prepared to plant or direct seed if we have one. The spruce budworm epidemic and the fire hazard of its aftermath are ecological phenomena sufficient by themselves to force us into readiness and willingness to use artificial regeneration or else to forsake any plans for intelligent intensive management.

Money motivates management. Therefore, benefits to the landowners from artificial regeneration should exceed the costs and until they do, there will be little enthusiasm for it. Changes could be made in the Forestry Incentives Program to encourage more intensive reforestation on small woodlots, such as cost-sharing for site preparation and acceptance of direct seeding as a substitute for planting. Cost accounting procedures by large landowners who process their own wood may undergo changes when their balance sheets between harvesting and regeneration show a growth-drain ratio which necessitate increased reforestation to support their wood demands.

Research Needs:

Research needs in artificial regeneration should be considered within the total context of intensive management. What is needed most is new knowledge which will help forest landowners make a profit growing trees under the many sociological, economic, and biological constraints with which they must contend.

A culturally sound and economically attractive method of reforestation may have limited utility if it is flawed by a factor which makes it unacceptable to society. We have recently been shown some classic examples in this regard, such as the curtailment of direct seeding by regulations restricting the use of chemical rodenticides and seed protectants. Also, tree planting following clearcutting of large areas, though profitably appealing and professionally preferred, has offended the public and produced its own problems. Other, less notable, cases could be cited but these should suffice to accentuate the need for a new forest research perspective -- a perspective which includes people as well as practices. We must learn how to make what we do in the management of forests seem right to others, which points to the need for "communications research."

When several methods of regeneration have proven culturally successful and the decision as to which to use is an economic one, then information on costs, both cash and compounded, must be made available on all options and their supplemental or supporting activities. Because of the dearth of such information on regenerating our northern species, research in the economics of reforestation is recommended.

If we measured what we know against what we do not know of the ecology of our northern forest types and species, the results should shock us from any complacency with our existing efforts in biological research. The opportunities and needs for such research are many but I will name only one subject-matter area -- forest genetics -- for the silviculture of intensive management must be based upon genetic principles. The intensive selection and breeding of trees require artificial regeneration, which in turn is dependent upon the application of genetics to provide it with high quality seed (or other propagules) from good genotypes. Hence, research in forest genetics must receive top priority and should be planned and supported on a Cooperative basis as it has been in the South.

CONCLUSION

I have presented this overview of our reforestation situation, not to be critical or condemnatory of it, but to place it in perspective. For I sincerely believe that unless the regeneration phase of forestry is given proper consideration, the management of our northern forest types cannot become truly intensive.

Foresters must eventually emulate those achievements of their agricultural counterparts who have developed a successful culture of "cultivated food plants." Fiber from the forests of the Northeast will perhaps some day make its mark in the millenium of mankind when the species from which it comes, though still resembling their wild ancestors, can be called "biological monuments" to man's efforts to tame them through intensive management.

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LARGE SCALE SOFTWOOD PLANTING OPERATIONS IN NEW BRUNSWICK

by M. K. Barteaux, Chief Forest Management Section, Forests Branch, Department of Natural Resources, Fredericton, N. B.

Abstract

New Brunswick is presently planting 20,000 ac. per year and expects to be planting nearly 60,000 ac. per year by 1979. Total productive forest area is 15,000,000 acres. The program is directly related to projected industrial demand and other forest uses. Plantations are established by scarification and planting of paper pot containers and bare root stock.

Introduction

This presentation will depict the softwood planting program being implemented in the Province of New Brunswick, Canada. I will outline briefly, past and present efforts, future plans, reasons for the program, techniques involved and lastly provide some observation of results and problems.

The Province comprises some 15,000,000 acres of productive forest land. Of this approximately 7,000,000 acres is Provincial Government controlled and the remainder freehold. My remarks will be slanted to Government activity although softwood planting is relatively similar on all lands.

Considering the Provincial situation, planting on an operational basis has been taking place since the early 1960's and has increased from 5,000 acres per year to 15,000 acres in 1975. This year approximately 20,000 acres will be planted and by 1979 (only 3 years) nearly 60,000 acres, representing approximately 1/3 of the annual cutover. Planted acres are expected to level off at this date or be reduced by thinning and seeding.

Why a Softwood Planting Program

This is the first question the administrators of any province, state or private agency must ask themselves before embarking on a program costing millions of dollars annually. In New Brunswick it is simply a matter of supply and demand. The forest industry is essential to the Province and the Government has committed itself to a program of development and proper management. The demand for wood has been calculated and projected; the potential of the Province to meet the demand has been assessed and projected. A necessary third step has been the adjustment of demand to conform with potential supply by controlling industrial activity through mutual cooperation and regulations - the net result being a clear indication of large scale planting effort required along with other silvicultural treatments. This calculation and projection is not an easy exercise and I will not go into the numerous considerations including economic feasibility, natural regeneration, natural growth rates, plantation growth rates, annual allowable cut determination, other forest uses, industrial expansion, land tenure, politics, social impacts, etc. But, it should be re-emphasized that this is the necessary first approach to any planting or reforestation program and it must be "sold" to all those concerned or at least a substantial majority. New Brunswick is plagued with the spruce budworm and this calculated effect on the forest has also been very influential in dictating the planting program.

Planting Techniques

Softwood planting stock for government controlled land consists at present of 50% bare root and 50% greenhouse grown paper pot containers. This will change to 70% containers and 30% bare root when the 30,000,000 seedling goal (30,000 acres) is reached in 1979.

Other than the fact that they are an acceptable type of planting stock, there are basically two reasons for a high proportion of containers (1) encouragement of a more stable labour force (planters) by producing stock which can provide employment throughout the season rather than large bare root operations in the spring and fall (summer planting of bare root represents a survival problem in New Brunswick); (2) to provide short term flexibility with respect to varying species and quantity requirements of forest managers and possible nursery crop failures. Container stock can be produced in 4-5 months whereas bare root is restricted to production schedules of 2-4 years.

All planting stock is now produced in a central nursery and delivered to District Forest Managers. By 1979 satellite nurseries are planned for several regions. Custom made truck boxes are used for transportation. Costs of growing nursery stock (excluding capital investment) are in the vicinity of $35/M for both container and bare root. However, it is felt that container stock can be significantly reduced through improving nursery expertise and large volume material purchases.

Species composition is now 45% black spruce, 40% jack pine and 15% miscellaneous. These two species are resistant to spruce budworm and are native species currently believed to be best suited to a broad range of New Brunswick sites. However, experience and study indicate a different proportion because of growth-site response. In other words these species may not provide the volume at rotation age required to meet demand projections. By 1979 the proportion should be less than 40% black spruce, jack pine approximately 25% and the remainder white spruce, red pine and larch.

Obtaining sufficient quantities of seed is not a simple accomplishment in the Province and necessitates intensive planning and expenditure of reforestation dollars. A new and modern seed extraction plant and storage facilities are under construction this summer. Also a tree improvement program was initiated in 1974 and we are planning for ever improving sources of quality seed.

Actual planting sites are selected by District Forest Managers who base their selection on regeneration surveys after cutover, projections of annual allowable cut and professional opinion as to site-species productivity. It is recognized that these professional opinions are often less than satisfactory and study of site-species productivity has commenced to devise a systematic and feasible technique for measuring the most important parameters involved.

Most planting is carried out on scarified areas. The different types of scarification equipment are as follows in descending order of use.

- Barrell scarifier
- Finnish plow
- Marden roller
- Crusher
- Bracke
- Root rake
- Disc trencher
- Prescribed burning
- Full tree logging

Costs vary from $16-$60 per acre (including capital purchase) depending on site and equipment efficiency. An attempt is being made to reduce the variety of equipment to those few preparing a suitable site at least cost.

Planting is nearly all by hand labour with payment on a pieces rate basis. Planting costs range from $20-$40 per acre.

The first large scale operational use of herbicides will be attempted this year on some 4,000 acres of plantation.

Summary

To conclude a softwood planting program such as New Brunswick is embarking on is not the oversimplified procedure I have perhaps presented. Ideas, techniques, problems and even objectives change and represent a continuing challenge to foresters. For example New Brunswick is now facing the problem of under utilization of its hardwood resource. This wood supply will and is influencing demand-supply projections for softwood. Further, uncut hardwood within clear-cuts is a serious hindrance to scarification treatment and reduces the available sites for plantation establishment.

Cost per acre of planting is too high but can be reduced by standardizing one or two systems of growing stock and perhaps only two or three systems of scarification.

Finally, accurate site identification and scientific assessment of plantation survival and development have been recognized as essential components of a successful and feasible planting program.

HARDWOOD PLANTING IN SOUTHERN ONTARIO

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ABSTRACT

Successful hardwood afforestation is possible provided the following conditions can be met: (1) a deep, moist but well-drained soil; (2) intensive site preparation, preferably plowing and disking of the total plantation area; (3) careful planting of healthy, sturdy planting stock; (4) effective weed control for at least the first two and preferably three years after planting; and (5) control of rabbits and mice.

INTRODUCTION

Most hardwood species can be planted successfully provided the proper conditions are met. However, many hardwood species are very exacting in their climatic and site requirements and require intensive cultivation during the early years after planting. Therefore, successful hardwood establishment is generally more difficult and certainly more expensive than planting of coniferous trees.

In the past, hardwood plantations have often failed because foresters and tree planters had insufficient knowledge of the site requirements of the various species, and planting techniques developed for planting conifers have proved to be unsuitable for hardwood planting.

Although our knowledge of the factors affecting hardwood establishment and growth is still rather limited, sufficient information is available now to recommend hardwood planting if the following conditions are met.

SELECTION OF THE PLANTING SITE

The most important factor in establishing hardwood plantations is the selection of a suitable planting site (von Althen 1964). For satisfactory establishment and growth, hardwood species demand a deep, fertile, moist but well-drained soil, and even land that may produce fair farm crops is not always suited to good hardwood growth. In southern Ontario, good hardwood sites will usually be found along creeks and streams, on lower slopes and in depressions where topsoil has accumulated, in abandoned orchards or gardens, and in agricultural fields where the A and B horizons are at least 18 in. (45.72 cm) deep (von Althen 1972). Hardwoods will never produce high-quality timber when planted on dry, exposed slopes and ridges, or in areas where the topsoil is shallow and the subsoil consists of heavy compacted clay.

Since sites for afforestation are generally available only because the land is unsuitable for agriculture, it would be unrealistic to envision the establishment of large hardwood plantations. At the same time, most available afforestation sites contain some small areas that are capable of growning high-quality hardwood timber. These are the sites on which hardwoods should be planted.

SITE PREPARATION AND WEED CONTROL

The second most important factor in successful hardwood plantation establishment and early growth of seedlings is the control of herbaceous competition. Since the effectiveness of weed control during the first few years after planting depends largely on the intensity of site preparation, the most intensively prepared sites will generally require the least post-planting weed control. If Princep[1] is used in post-planting weed control, site preparation is especially important for the successful establishment of those hardwood species that are highly susceptible to Princep damage at dosages necessary for the effective control of deep-rooted perennial weeds. For example, to control goldenrod (Solidago spp.), wild aster (Aster spp.) and other deep-rooted weeds effectively, applications of 4-8 lb per acre (4.8-8.96 kg/ha) of active Princep are required. However, cottonwood (Populus deltoides Bartr.) and white ash (Fraxinus americana L.) seedlings may be damaged by applications of more than 3 lb of active Princep per acre (3.36 kg/ha). Therefore, if the deep-rooted perennial weeds are not eliminated before the trees are planted it is very difficult, if not impossible, to control them after planting. However, once the perennial weeds have been eliminated by site preparation, an annual application of 3 lb per acre (3.36 kg/ha) of active Princep will generally prevent re-establishment or at least keep weed competition to an acceptable level (von Althen 1976).

Site preparation may take the form of plowing and disking or chemical eradication of the competing vegetation. The choice of method will depend on the condition of the soil, topography and accessibility, density and composition of the existing cover, and last but not least, on the cost of the various methods under consideration. Under no circumstances, however, should the success of a plantation be sacrificed for an initial saving in the cost of site preparation and weed control.

Plowing and disking of the total plantation area is the best method of site preparation developed to date because it offers advantages not obtainable by any other method: it destroys all weeds, including the deep-rooted perennial species; it stimulates microbial activity; it loosens the soil and improves aeration and water infiltration; and it incorporates plant material into the soil, thereby improving the nutrient status and organic content of the soil.

Where plowing and disking of the total plantation are not feasible or desirable because the soil may be subject to erosion or the planting site may be partially treed, strips at least 6 ft (182.88 cm) in width may be plowed and disked, rototilled, or sprayed with herbicides, and the trees planted along the middle of these strips. However, site preparation in strips generally is less effective in promoting tree growth than is complete mechanical site preparation. The latter should, therefore, be used wherever possible.

Post-planting weed control for the first two or three years after planting is an absolute necessity for successful hardwood afforestation. Manual and mechanical methods of weed control have proven very successful but the frequency of operations required for effective control makes these methods rather expensive. Herbicides offer more economical control, but many hardwood species are highly susceptible to damage by the dosages necessary for effective control. Although many herbicides are currently available and new chemicals are marketed every year, Princep remains one of the most useful and reliable herbicides in hardwood afforestation.

Each tree species has its own herbicide tolerance. This tolerance is modified by the texture and moisture of the planting soil, seedling age, length of establishment, and time and method of application. To provide the best possible weed control without causing seedling damage, all dosages must therefore be carefully metered. A preliminary guide to the application of Princep in hardwood plantations is listed in Table 1.

Quackgrass (Agropyron repens [L] Beauv.) is one of the most competitive weeds and its elimination by mechanical means generally requires several years of intensive cultivation. Recently Rohm and Haas have marketed the herbicide "Kerb" which effectively kills all grasses including quackgrass. Kerb is very selective in its action. If applied properly it will kill grasses but will not kill or harm either trees or broad-leaved weeds. It may

Table 1. Preliminary guide to applying active Princep in hardwood plantations established on fully cultivated, former agricultural land

Species	Soil texture	Maximum allowable application of active Princep[a]	
		Shortly after planting (lb/acre)[b]	In the spring of the 2nd and 3rd years (lb/acre)[b]
Black walnut	loam	6	4
(*Juglans nigra* L.)	clay-loam	8	4
Butternut	loam	6	4
(*Juglans cinerea* L.)	clay-loam	6	4
Silver maple	loam	4	3
(*Acer saccharinum* L.)	clay-loam	5	3
	clay	6	3
Black-locust	loam	4	3
(*Robinia pseudoacacia* L.)	clay-loam	5	3
	clay	6	3
White ash	loam	3	3
(*Fraxinus americana* L.)	clay-loam	3	3
	clay	3	3
Basswood	sand	4	3
(*Tilia americana* L.)	loam	4	3
	clay-loam	5	3
Red oak	sand	5	3
(*Quercus rubra* L.)	loam	6	3
Black cherry	sand	3	3
(*Prunus serotina* Ehrh.)	loam	3	3
Sugar maple	sand	2	2
(*Acer saccharum* Marsh.)	loam	2	2

[a] Commercial grade of Princep (simazine) is available at 50 and 80 percent active chemical.

[b] 1 lb/acre = 1.12 kg/ha.

Note: 1 lb active Princep = 2 lb Princep 50W.
1 lb active Princep = 1.25 lb Princep 80W.

therefore be broadcast over the trees, like Princep, without shielding the trees or directing the spray away from them. In our experiments 1.5–2.0 lb/acre (1.68–2.24 kg/ha) of active Kerb, applied in November, killed 95% of all grasses during the winter. As a site preparation treatment, Kerb should be broadcast over the total area in late October or early November. Treated areas may include both plowed and disked land containing quackgrass rhizomes which will sprout again, and grassy fields or pastures which have not been plowed.

PLANTING STOCK

The success of any plantation will also depend on the quality and suitability of the planting stock. Good planting stock should be sturdy and have a well-branched root system (Limstrom 1963). In a study of the quality of hardwood planting stock, seedling size was much more important than seedling age (von Althen 1969). Not only did the largest trees of either 1+0 or 2+0 seedlings always grow faster than the smaller trees, but the 1+0 seedlings with large root-collar diameters generally survived and grew better than 2+0 seedlings of equal size. Table 2 lists recommendations for planting stock grades for the most commonly planted hardwood species in Ontario. Tree planters have often expressed a preference for large transplant stock, believing that planting large trees would eliminate the need for site preparation and weed control. Although this probably is true for individual,

Table 2. Recommended planting stock grades for hardwoods planted in Ontario

Species	Length of stem		Root-collar diameter	
	Minimum (in.)[a]	Preferred (in.)[a]	Minimum (in.)[a]	Preferred (in.)[a]
Silver maple	8	12	0.20	0.25
Basswood	8	12	0.20	0.25
Red oak	8	12	0.20	0.25
White ash	8	12	0.20	0.25
Black walnut	8	12	0.25	0.35

[a] 1 in. = 2.54 cm.

large trees, those 3-4 ft (91.44-121.92 cm) high and up to five years old grew very poorly when planted in a weed-infested soil without prior site preparation or without subsequent weed control (von Althen 1974). Since transplant stock is very expensive to produce, transport and plant, and since growth of seedlings on unprepared sites is generally inferior to that of seedlings planted in plowed and disked soils treated with herbicides, it is much more economical to spend the available money on site preparation and weed control than on producing large transplant stock.

PLANTING METHODS

Small hardwood seedlings may be planted either with a planting machine or by hand using the wedge method, while large trees with spreading root systems are most efficiently planted in holes made with a posthole auger. Care must always be taken that the trees are planted at normal depth and that the soil is well packed around the roots. All trees should be planted in an upright position since leaning hardwood seedlings often develop a new vertical shoot from the root collar, necessitating the removal of the original stem by pruning and thereby losing valuable height increment (Erdmann 1966).

DIRECT SEEDING

Establishing hardwoods by direct seeding has been investigated as an alternative method to planting of nursery-grown stock. Advantages of direct seeding over planting are reduced planting costs and elimination of planting injury. The greatest disadvantage is the uncertainty of satisfactory establishment. Hardwood species with relatively small seeds such as ash and birch were generally found to be unsuitable for direct seeding and only the oaks and black walnut showed any promise of success (Winch 1937, Scholz 1964, Bjorkbom 1969). Until more successful seeding methods are developed, planting nursery-grown seedlings guarantees better plantation establishment than does direct seeding.

FERTILIZATION

Since low fertility is one of the characteristics of land withdrawn from agriculture, fertilization appears to offer possibilities of improving tree growth on nutrient-deficient sites. Although Mitchell and Chandler (1939) showed that growth of hardwood stands could be improved significantly by nitrogen fertilization, the growth response of hardwood seedlings to fertilization at time of planting has often been disappointing (Cummings 1941, McComb 1949, Burke and Williams 1973, Geyer 1974). The failure of fertilization at time of planting to improve seedling growth significantly was probably the result of one or more of the following conditions: (1) the planting soils contained a sufficient supply of available nutrients to satisfy the nutrient requirements of the newly planted seedlings; (2) the applied fertilizer either did not reach the roots or was not taken up by the seedlings; (3) the dosages of fertilizer applied were too small to produce measurable growth responses; (4) soil physical conditions, e.g., poor drainage, were limiting growth; and (5) a deficiency in nutrients other than those applied was more limiting to seedling growth than was the deficiency in the applied nutrients.

Until more information is available, fertilization at the time of planting is inadvisable because it may do more harm than good by increasing weed competition and adding to the pollution of rivers and lakes. Fertilization is also expensive and money spent on fertilizer applications at the time of planting could be put to better use by intensifying site preparation and weed control treatments which have proven beneficial to hardwood plantation establishment and seedling growth.

RODENT CONTROL

Tree girdling by mice and browsing by rabbits can cause heavy damage in hardwood plantations (von Althen 1971). The most common method of mouse control has been the broadcast application of poisoned grain. However, this method generally provides only short-term relief. Recently, Radvanyi (1974) developed a mouse poison feeder station which provides longer lasting control. Control of rabbit browsing may be obtained by painting repellents on the trees. However, these methods are rather expensive for the degree of protection they afford. The best protection against rodent damage is the elimination of weeds; this deprives the animals of shelter and food and makes the plantation a hostile environment for rodent survival and reproduction. Also, weed control generally increases seedling growth, and fast-growing trees are less vulnerable to rodent damage because they soon outgrow the danger.

SUMMARY

The requirements for successful hardwood plantation establishment are:

1. a deep, moist but well-drained planting soil
2. plowing and disking the total area
3. healthy, sturdy planting stock
4. careful planting
5. effective weed control for the first two or three years after planting
6. rodent control where necessary

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FOOTNOTE

[1] Identification of commercial products is for information only, and does not constitute endorsement by the Great Lakes Forest Research Centre.

DIRECT SEEDING IN NORTHERN FOREST TYPES

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Abstract

Two direct-seeding experiments were established to determine the effect of time of seeding (spring 1962 versus fall 1962), type of seedbed (prepared versus unprepared), and species (red pine (Pinus resinosa Ait.) versus white spruce (Picea glauca (Moench) Voss)) upon the success attained in the reforestation of a pine-barren site and a recently burned-over forest site in eastern Maine. A split-split-plot experiment with 0.75-acre treatment plots was replicated three times on each site. Seedbeds on the pine barren were prepared by disking with a Rome disk harrow and seedbeds on the burn, by scarifying with a bulldozer. Treatment plots were broadcast sown by hand at a seeding rate of 50,000 viable seed per acre. All treatments on the pine barren except those established on unprepared seedbeds, all of which were failures, resulted in the establishment of moderately-stocked to over-stocked stands five years after seeding. All treatments on the burn produced adequately stocked stands initially, however, by the fifth growing season competing vegetation had reduced the average milacre stocking percent of most treatments to less than 50 percent.

Publication of guidelines for direct seeding loblolly pine (Pinus taeda L.) by Mann and Derr (1959, longleaf pine (Pinus palustris Mill.) by Derr and Mann (1961), and a paper on the direct seeding of conifers presented at the Winter Meeting of the New England Section of the Society of American Foresters in March 1961 by Abbott (1961) resulted in stimulating anew an interest in direct seeding among forest land managers in Maine. Sufficient interest was generated for the Maine Agricultural Experiment Station, Bureau of Forestry, Bureau of Sport Fisheries and Wildlife, St. Regis Paper Company, Standard Packaging Corporation, and Georgia-Pacific Corporation to collaborate in the establishment of two experiments in the spring of 1962 to study the applicability of direct seeding in northern forest types. The experiments were established specifically to determine the respective effects of time of seeding (spring 1962 versus fall 1962), type of seedbed (prepared versus unprepared), and tree species (red pine (Pinus resinosa Ait.) versus white spruce (Picea glauca (Moench) Voss)) upon the success attained in the reforestation of a pine-barren site and a recently burned-over forest site. Early results of both experiments have been reported by Griffin, DeCoster, and Collom(1965 and Collom(1965). This paper summarizes the results of the experiment on the pine-barren site through the 1967 growing season and the results of the experiment located on the burned-over forest site through the 1966 growing season.

LOCATION AND DESCRIPTION OF EXPERIMENTAL AREAS

The experiment on the pine barren was located in the northeast corner of Township 30 M.D., Washington County, Maine. The soil, a well- to excessively-drained Colton sandy loam supported a dense stand of vegetation composed principally of lowbush blueberry (Vaccinium angustifolium Ait.), lambkill (Kalmia angustifolia L.), wintergreen (Gaultheria procumbens L.), sweet fern (Comptonia peregrina (L.) Coult.), and reindeer moss (Cladonia rangiferina (L.) Web.)

The experiment on the burned-over area was located near the southeast side of Duck Lake in Township 4 N.D., Hancock County, Maine. The soil was a well-drained Hermon very stony loam. Previous to a wildfire in the summer of 1960, the area supported a forest stand composed principally of eastern hemlock (Tsuga canadensis (L.) Carr.) red spruce (Picea rubens Sarg.) and balsam fir (Abies balsamea (L.) Mill.). Trees of merchantable size were being harvested when the fire occurred. The fire, covering approximately sixty acres, burned to the mineral soil. Vegetation was still quite sparse in the spring of 1962. Many of the fire-killed trees had been blown down and others were in the process of falling. Sarsaparilla, (Aralia hispida Vent.), bracken fern (Pteridium aquilinum var. latiusculum (Desv.) Underw.), raspberry (Rubus idaeus var. aculeatissimus Regel and Tiling), fireweed Epilobium angustifolium L.) and numerous grasses began to appear on the burn in the summer of 1962. Tree species consisted principally of quaking aspen (Populus tremuloides Michx.), bigtooth aspen (Populus grandidentata Michx.), pin cherry (Prunus pensylvanica L. f.), paper birch (Betula papyrifera Marsh.) and yellow birch (Betula alleghaniensis Britton). Sprout clumps of American beech (Fagus grandifolia Ehrh. and red maple (Acer rubrum L.) occurred sporadically.

PROCEDURE

Experimental Design

A split-split-plot experiment was replicated three times on each experimental area. Each major block was divided into two 3-acre main plots; each main plot, into two 1.5-acre subplots; and each subplot, into two 0.75-acre minor plots. Within a major block, times of seeding were assigned at random to the main plots; types of seedbed, to the subplots; and tree species, to the minor plots.

While the respective treatments were applied as uniformly as possible over the entire acreage of each minor plot, measurements of results were confined to a 0.5-acre area in the center of the minor plot. Thus, each treatment was surrounded by a 0.25-chain buffer strip.

Preparation of Seedbeds

Seedbeds on the pine barren were prepared with a Rome disk harrow pulled by a D-7 Caterpillar. The plots were disked twice. The second disking accomplished an almost complete break-up of the thick root mass turned up by the first disking. Plots sown in the spring were disked in May and those sown in the fall, in September.

Seedbeds on the Duck Lake Burn were prepared by working a bulldozer through the plots in a zigzag pattern by alternately locking the tracks. The partial turning of the bulldozer chewed up much of the debris and exposed some mineral soil. However, large boulders and down timber precluded the attainment of a uniformly prepared seedbed similar to that obtained with the Rome disk harrow on the pine barren. Plots seeded in the spring were prepared in June 1962 and those seeded in the fall, in September 1962.

Treatment of Seed

Seed from red pine and white spruce seed lots collected in the Lake States was used in both spring and fall seedings. Germination percents of the red pine and white spruce seed sown in the spring were 78 percent and 70 percent and of those sown in the fall, 85 percent and 51 percent respectively.

The seeds were coated for protection against losses to mammals and birds with 50 percent wettable endrin powder (2 percent to weight of seed), 75 percent wettable Arasan powder (1 percent to weight of seed), Dow Latex 512-R (1 part latex to 9 parts water) and enough aluminum paint flakes to cover the seed uniformly.

Seeding of Minor Plots

Within each minor plot, twenty square milacre observational plots were established at one-half chain intervals. While the observational milacres on the pine barren could be located systematically, some of those on the Duck Lake Burn had to be located irregularly to avoid heavy accumulations of debris.

Within each observational milacre, twenty seed spots were located systematically and marked with wooden dowels. The seed spots were seeded by dropping five seeds around each dowel. Thus, the seeding rate on the observational milacres in terms of viable seed per milacre was the same as the germination percent of the seed sown as given above.

The remaining 730 milacres in each minor plot was broadcast sown at the rate of 50 viable seeds per milacre. To obtain an even distribution of seed, the minor plots were divided into four strips of equal size and each strip was broadcast sown by hand with one-fourth of the total amount of seed sown on the plot. On the pine barren, spring-sown plots were sown May 30-June 5, and fall-sown plots, October 1-2. On the Duck Lake Burn spring-sown plots were sown June 12-14, and the fall-sown plots, October 10-13.

Small Mammal Populations

Small mammal census plots were established on an undisturbed site in each experimental area in May 1962. The census plot on the pine barren measured 100 by 125 feet and the one on the Duck Lake Burn, 125 by 175 feet. Sherman live traps were stationed at the intersections of a 25 by 25-foot grid system. Population censuses were conducted during the spring and fall of 1962, 1963, and 1964 (Ladd 1965).

No animals were trapped on either the census plot or additional spot-check trapping sites located on the pine barren. The absence of small mammals on the pine barren was attributed to a lack of suitable cover.

The small mammal population on the Duck Lake Burn increased as the density of the herbaceous vegetation increased. The censuses indicated a population per census plot of one deer mouse (Peromyscus maniculatus) in May 1962, three red-backed voles (Clethrionomys gapperi) in October 1962, no animals in June 1963, sixteen deer mice plus four red-backed voles in October 1963, and thirteen deer mice in August 1964 (Ladd 1965).

Weather

Since both experimental areas were within a twenty-mile radius of the Fire Danger Weather Station maintained by the Bureau of Forestry at Beddington, Maine, the weather was probably quite similar to that recorded at the Station. The weather during the 1962 and 1963 growing seasons was noticeably different in two respects. Rainfall in May 1963 (6.44 inches) totaled 4.74 inches more than that in May 1962 (1.70 inches). The average air temperature in July 1963 (69°F) averaged eight degrees higher than that in July 1962 (61°F). Thus, the weather was probably more favorable for prompt germination and early establishment of seedlings in 1963 than in 1962.

Inventories

Inventories were made of germination, seedling survival, and seedling mortality on the observational milacres of both experiments in the spring and fall of 1962, 1963, and 1964 (Collom 1965). The final inventory of the observational milacres on the pine barren was made in late July 1967 when the spring-sown and fall-sown plots were in their sixth and fifth growing season respectively. The final inventory of the observational milacres on the Duck Lake Burn was made in late August 1966 when the spring-sown and fall-sown plots were in their fifth and fourth growing season respectively. Concurrently with the last inventory of the observational milacres, inventories were made of an additional 100 circular milacre plots (hereinafter referred to as inventorial milacres) located systematically in each of the 0.5-acre minor plots. When an inventorial milacre overlapped an observational milacre, the location of the inventorial milacre center was moved eight feet from the boundary of the observational milacre.

RESULTS

Pine Barren

Germination on spring-sown prepared seedbeds began prior to June 29, 1962 and on fall-sown prepared seedbeds prior to May 26, 1963. In both years, germination on unprepared seedbeds was not evident until after germination on prepared seedbeds was well underway.

By the fall of 1964, seedling mortality expressed as a percentage of stocking ranged from a low of 36 percent for red pine on prepared seedbeds to a high of 82 percent for white spruce on unprepared seedbeds. Twenty-four percent of the total seedling mortality on prepared seedbeds and 29 percent of the total seedling mortality on unprepared seedbeds were attributed to unknown causes. Seventy-three percent of the total seedling mortality on prepared seedbeds was attributed to frost heave (54 percent), drought (12 percent), and heat injury (7 percent). Seventy percent of the total seedling mortality on unprepared seedbeds was attributed to drought (47 percent), insects (18 percent) and heat injury (5 percent). In September 1964, red pine tree percentages, i.e. the number of live seedlings present for each 100 viable seeds sown, averaged 5.3 on unprepared seedbeds and 24.6 on prepared seedbeds. White spruce tree percentages averaged 1.9 on unprepared seedbeds and 12.7 on prepared seedbeds (Collom 1965).

The average number of seedlings per observational milacre and percent of observational milacres stocked with a minimum of one, two, five, and ten seedlings respectively in August 1963, September 1964, and July 1967 are recorded for each treatment on the pine barren in Table 1. Analysis of variance of the 1967 data found the effect of type of seedbed and the effect of species to be highly significant. Although more seedlings usually resulted from fall-sown seed than from spring-sown seed, the effect of time of seeding proved to be nonsignificant.

The inability of white spruce to become established on an undisturbed pine-barren seedbed and the relative poor vigor of the white spruce seedlings that managed to become established on prepared seedbeds were readily apparent in August 1963. Nevertheless, in July 1967 -

Table 1. - Average number of seedlings per observational milacre and percent of observational milacres stocked with a minimum of one, two, five and ten seedlings respectively for each treatment on the pine barren in August 1963, September 1964, and July 1967.

	Seeded spring 1962				Seeded fall 1962			
Time of observation and stocking level	Prepared seedbed		Unprepared seedbed		Prepared seedbed		Unprepared seedbed	
	P[a]	S[b]	P	S	P	S	P	S
				Number[c]				
Oct. 1962	13.4	7.1	6.3	1.5	-	-	-	-
Aug. 1963	20.3	6.6	5.5	0.7	36.2	23.5	5.1	1.6
Sept. 1964	16.0	3.3	4.8	0.6	24.5	10.5	3.8	1.5
July 1967	11.4	1.8	2.5	0.1	16.2	7.5	1.5	0.2
				Percent[d]				
Aug. 1963								
One seedling	100	95	92	40	100	98	90	58
Two seedlings	100	88	85	20	100	98	83	32
Five seedlings	98	65	47	27	100	97	58	15
Ten seedlings	93	30	15	0	97	83	30	2
Sept. 1964								
One seedling	100	87	90	33	100	95	85	50
Two seedlings	100	72	75	13	100	90	78	33
Five seedlings	100	25	38	0	98	73	37	7
Ten seedlings	87	5	13	0	93	48	5	0
July 1967								
One seedling	100	68	72	7	95	85	55	12
Two seedlings	98	48	53	0	95	72	37	3
Five seedlings	83	12	15	0	92	45	7	0
Ten seedlings	58	0	3	0	75	18	0	0

[a] Red pine.

[b] White spruce.

[c] Average of sixty observational milacres (twenty milacres in each of three replications) per treatment.

[d] Percent of the sixty observational milacres stocked with the specified minimum number of seedlings.

the sixth and fifth growing season for the spring-sown and fall-sown plots respectively - the number of white spruce seedlings on the spring-sown and fall-sown prepared seedbeds combined averaged 4.7 seedlings per observational milacre with 77 percent and 60 percent of the milacres being stocked with a minimum of one seedling and two seedlings respectively.

In July 1967, the number of red pine seedlings on the spring-sown and fall-sown unprepared seedbeds combined averaged 2.0 seedlings per observational milacre with 64 percent and 45 percent of the milacres being stocked with a minimum of one seedling and two seedling respectively. In contrast, the number of red pine seedlings on the combined spring-sown and fall-sown prepared seedbeds averaged 13.8 seedlings per observational milacre with 88 percent and 67 percent of the milacres being stocked with a minimum of five and ten seedlings respectively.

Regardless of species, the growth in height of seedlings on prepared seedbeds was greater than that of seedlings on unprepared seedbeds. In October 1964, the average maximum height (based on measurements of the tallest seedling on each observational milacre) of seedlings on prepared seedbeds (0.18 feet) was significantly greater than that of seedlings on unprepared seedbeds (0.11 feet) and the average maximum height of red pine seedlings was significantly greater than that of spruce seedlings (Collom 1965). In July 1967, the average maximum heights of red pine seedlings on prepared and unprepared seedbeds were 1.36 feet and 0.28 feet respectively. At that time the average maximum heights of white spruce seedlings on prepared and unprepared seedbeds were 0.66 feet and 0.35 feet respectively. By June 1976, red pine on the prepared seedbeds had reached a maximum height of around 15 feet while most of the white spruce on prepared seedbeds and most of the red pine on unprepared seedbeds were still less than 5 feet tall.

The average number of seedlings per inventorial milacre and percent of inventorial milacres stocked with a minimum of one, two, five, and ten seedlings respectively in July 1967 are recorded for each treatment on the pine barren in Table 2. While the effects of both type of seedbed and species were highly significant, the effect of time of seeding was nonsignificant.

Table 2. - Average number of seedlings per inventorial milacre stocked with a minimum of one, two, five and ten seedlings respectively for each treatment on the pine barren in July 1967.

	Seeded spring 1962				Seeded fall 1962			
	Prepared seedbed		Unprepared seedbed		Prepared seedbed		Unprepared seedbed	
Stocking level	P[a]	S[b]	P	S	P	S	P	S
				Number[c]				
	9.81	1.60	1.01	0.04	11.30	4.58	0.14	0.04
				Percent[d]				
One seedling	85	50	32	3	81	61	5	3
Two seedlings	78	32	17	0	77	50	2	1
Five seedlings	59	7	6	0	59	28	1	0
Ten seedlings	24	2	2	0	39	13	0	0

[a] Red pine.

[b] White spruce.

[c] Average of 300 inventorial milacres (100 milacres in each of three replications) per treatment.

[d] Percent of the 300 inventorial milacres stocked with the specified minimum number of seedlings.

The number of red pine seedlings on spring-sown and fall-sown unprepared seedbeds combined averaged only 0.5 seedlings per inventorial milacre with only 19 percent and 10 percent of the milacres being stocked at the one- and two-seedling level respectively. On spring-sown and fall-sown prepared seedbeds, the number of red pine seedlings averaged 10.6 seedlings per inventorial milacre with 83 percent and 78 percent of the milacres being stocked at the one- and two-seedling level respectively.

Duck Lake Burn

On the Duck Lake Burn, germination on prepared and unprepared seedbeds began apparently at about the same time. The spring-sown seed began germination soon after June 29, 1962 and the fall-sown seed sometime prior to May 26, 1962.

By the fall of 1964, seedling mortality expressed as a percentage of stocking ranged from a low of 28 percent for red pine on both prepared and unprepared seedbeds respectively to a high of 53 percent for white spruce on prepared seedbeds. Thirty-one percent of the total seedling mortality on prepared seedbeds and 46 percent of the total seedling mortality on unprepared seedbeds were attributed to unknown causes. Fifty-four percent of the total seedling mortality on prepared seedbeds was attributed to drought (22 percent), frost heave (20 percent) and heat injury (12 percent). Forty-two percent of the total seedling mortality on unprepared seedbeds was attributed to drought (27 percent), heat injury (11 percent) and frost heave (4 percent). In September 1964, red pine tree percentages averaged 13.6 on unprepared seedbeds and 24.8 on prepared seedbeds. White spruce tree percentages averaged 11.8 on unprepared seedbeds and 12.7 on prepared seedbeds (Collom 1965).

The average number of seedlings per observational milacre and percent of observational milacres stocked with a minimum of one, two, five, and ten seedlings respectively in September 1963, September 1964, and August 1966 are given for each treatment on the Duck Lake Burn in Table 3. Analysis of variance of the 1966 data showed the effect of type of seedbed to be significant and the effect of species to be highly significant. The effect of time of seeding was not significant.

In August 1966, - the fifth and fourth growing season for the spring-sown and fall-sown plots respectively - the number of white spruce seedlings on spring-sown and fall-sown unprepared seedbeds combined averaged 3.1 seedlings per observational milacre with 63 percent and 55 percent of the milacres being stocked with a minimum of one seedling and two seedlings respectively. In contrast, the number of white spruce seedlings on spring-sown and fall-sown prepared seedbeds combined averaged 3.9 seedlings per observational milacre with 83 percent and 63 percent of the milacres being stocked with a minimum of one seedling and two seedlings respectively.

Table 3. - Average number of seedlings per observational milacre and percent of observational milacres stocked with a minimum of one, two, five, and ten seedlings respectively for each treatment on the Duck Lake Burn in September 1963, September 1964, and August 1966.

Time of observation and stocking level	Seeded spring 1962				Seeded fall 1962			
	Prepared seedbed		Unprepared seedbed		Prepared seedbed		Unprepared seedbed	
	P[a]	S[b]	P	S	P	S	P	S
				Number[c]				
Oct. 1962	17.8	3.7	19.1	6.9	-	-	-	-
Sept. 1963	16.2	4.1	15.0	5.8	33.5	14.3	10.4	8.9
Sept. 1964	13.8	3.2	12.0	4.9	27.1	10.6	9.6	8.4
Aug. 1966	10.1	2.0	4.9	2.7	14.1	5.8	2.7	3.5
				Percent[d]				
Sept. 1963								
One seedling	98	88	98	82	97	100	95	87
Two seedlings	98	73	98	70	97	98	80	83
Five seedlings	88	32	88	47	97	83	57	62
Ten seedlings	70	12	73	23	95	62	40	40
Sept. 1964								
One seedling	97	75	92	75	95	97	87	85
Two seedlings	97	65	92	58	95	90	73	77
Five seedlings	87	20	78	42	95	72	50	60
Ten seedlings	58	12	57	23	88	42	40	38
Aug. 1966								
One seedling	98	75	82	63	100	90	60	63
Two seedlings	95	53	68	52	100	73	55	58
Five seedlings	80	5	40	25	88	48	23	28
Ten seedlings	38	0	15	5	60	17	5	7

[a] Red pine.

[b] White spruce.

[c] Average of sixty observational milacres (twenty milacres in each of three replications) per treatment.

[d] Percent of the sixty observational milacres stocked with the specified minimum number of seedlings.

In August 1966, the number of red pine seedlings on spring-sown and fall-sown unprepared seedbeds combined averaged 3.8 seedlings per observational milacre with 71 percent and 62 percent of the milacres being stocked with a minimum of one seedling and two seedlings respectively. In contrast, the number of red pine seedlings on spring-sown and fall-sown prepared seedbeds combined averaged 12.1 seedlings per observational milacre with 98 percent and 67 percent of the milacres being stocked with a minimum of two and five seedlings respectively.

The average number of seedlings per inventorial milacre and percent of inventorial milacres stocked with a minimum of one, two, five and ten seedlings respectively in August 1966 are recorded for each treatment on the Duck Lake Burn in Table 4. Analysis of variance indicated the effect of type of seedbed to be significant. The effects of time of seeding and species were nonsignificant.

The number of white spruce seedlings on spring-sown and fall-sown unprepared seedbeds combined averaged 1.25 seedlings per inventorial milacre with 37 percent and 22 percent of the milacres being stocked at the one- and two-seedling level respectively. On spring-sown and fall-sown prepared seedbeds combined, the number of white spruce seedlings averaged 1.71 seedlings per inventorial milacre with 41 percent and 27 percent of the milacres being stocked at the one- and two-seedling level respectively.

The number of red pine seedlings on spring-sown and fall-sown unprepared seedbeds combined averaged 1.54 seedlings per inventorial milacre with 35 percent and 27 percent of the milacres being stocked at the one- and two-seedling level respectively. On spring-sown and fall-sown prepared seedbeds combined, the number of red pine seedlings averaged 3.43 seedlings per inventorial milacre with 59 percent and 44 percent of the milacres being stocked at the one- and two-seedling level respectively.

Table 4. - Average number of seedlings per inventorial milacre and percent of inventorial milacres stocked with a minimum of one, two, five, and ten seedlings respectively for each treatment on the Duck Lake Burn in August 1966.

	Seeded spring 1962				Seeded fall 1962			
	Prepared seedbed		Unprepared seedbed		Prepared seedbed		Unprepared seedbed	
Stocking level	P[a]	S[b]	P	S	P	S	P	S
	Number[c]							
	3.89	1.27	2.05	1.51	2.96	2.14	1.03	0.99
	Percent[d]							
One seedling	63	40	43	41	54	41	27	32
Two seedlings	53	25	33	25	45	28	20	19
Five seedlings	29	7	16	9	22	15	5	4
Ten seedlings	15	3	5	3	8	7	2	1

[a] Red pine.
[b] White spruce.
[c] Average of 300 inventorial milacres (100 milacres in each of three replications) per treatment.
[d] Percent of the 300 inventorial milacres stocked with the specified minimum number of seedlings.

DISCUSSION

The experiments were established in the spring and fall of the same year because of circumstances rather than by choice. Seeding in the fall and in the spring of the following year, inasmuch as the germination of both seedings would have then occurred under the same environmental conditions, would have provided a more valid test of the effect of season of sowing. Nevertheless, the results of both experiments indicate strongly that the season of sowing has little, if any, effect upon the success attained in the reforestation of pine-barren sites and recently burned-over forest sites. On sites where excessive losses of seed to small mammals and birds might occur, which apparently was not the case on the areas direct seeded in this study, fall seeding of untreated seed would be quite likely to result in failure. Fall seeding exposes seed to depredation by destructive agencies for longer periods of time than spring seeding. On the other hand, fall seeding not only eliminates the need to stratify seed prior to sowing but also ensures that seed will be in place on the site and ready to germinate as soon as conditions are favorable, thereby providing the resultant seedlings with the full length of the growing season in which to become firmly established. In practice, spring seeding may be accomplished too late, as happened in this study, to enable seedlings to make full use of the first growing season.

Pine barrens reforest so slow naturally that the process is almost imperceptible yet broadcast sowing white spruce and red pine seeds on disked seedbeds in the spring and fall at rates of 50,000 viable seeds per acre resulted in the establishment of moderately- to well-stocked stands of white spruce and over-stocked stands of red pine in the fifth and sixth growing season for spring-and fall-sown plots respectively. Red pine has the inherent ability to become established and to grow reasonably well on disked seedbeds. A surprising number of red pine seedlings was able to become established on unprepared seedbeds. On the other hand, white spruce, being much less drought resistant than red pine, failed to become established on unprepared seedbeds and white spruce seedlings on prepared seedbeds grew much more slowly in height than red pine seedlings on comparable seedbeds. Thus, white spruce cannot be recommended as being a species suitable for use in the reforestation of pine barrens.

The striking success obtained with red pine indicates strongly that pine barrens can probably be reforested successfully by broadcast sowing red pine seed at rates less than 50,000 viable seed per acre on seedbeds prepared less thoroughly than the seedbeds were in this study.

On the Duck Lake Burn, the average number of seedlings per milacre was significantly greater on prepared seedbeds than on unprepared seedbeds, however, the difference was not as great as that on the pine barren. Furthermore,both prepared and unprepared seedbeds were apparently suitable for the germination and establishment of both species for all treatment plots were adequately stocked with seedlings at the end of the third and second growing season for the spring-and fall-sown plots respectively. However, by the fifth growing season, severe competition of overtopping hardwood growth had reduced the seedling milacre stocking percents on the broadcast sown portions of all treatment plots, except the red pine on prepared seedbed plots, to below 50 percent. An adequate stocking of established seedlings could probably have been maintained on all treatment plots had the seedlings been released promptly by either cutting or deadening the overtopping vegetation with a herbicide. Such cultural treatments will usually be required to maintain an adequate stocking of a direct-seeded species on sites favorable to the natural establishment of other faster growing species.

Successful techniques for direct seeding the southern pines were developed only after many years of study involving experimentation followed by numerous field trials. The results of this study give no reason to doubt that an effort in the Northeast similar to that in the South would result in the development of reliable techniques for direct seeding the northern conifers.

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INTERMEDIATE CULTURAL PRACTICES

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What are these interesting sounding things? Are they theory, are they pie in the sky, fantasies of desk foresters - or are they the real McCoy - something the landowner needs if he is going to make his woodlands pay a return on his investment. To list briefly, shall we say they are pre-commercial treatments, marginal commercial treatments, commercial thinnings, pruning for improved quality and perhaps a few more that we all generally recognize.

Frankly, I have been fascinated by them since my grammar school years when I transplanted wild strawberries from a field and set them out in a weeded garden and saw them triple or more in size with this simple procedure; when I cut back scrub oak over-topping white pine reproduction and saw these trees easily surge upward above the poor quality hardwoods and the non-released pines die; when I planted a gravel bank on a north slope that had been barren of vegetation for years with hemlock I dug out of the woods and saw it become a vigorous young stand with a humus layer in a few short years.

And when I went to forestry school and found in the silviculture books the discussions of these principles, I felt as happy as Columbus when he didn't fall off the edge when he sailed westward.

That forestry school was many years ago and the time devoted to intermediate cultural practices was brief, and the field exercises or examples for us neophyte foresters to see, were practically non-existent, and I have a feeling they are in today's schools also. Researchers were a rare breed (and maybe still are) and they had not proliferated to the degree they have now where everything under the sun is being probed and researched and a good job done on it - but the universal complaint now as then - and justifiably so, how do we get this research read and put into practice by the forester - it just is not being done.

Let me digress just a moment. Foresters are, and try to be, all things to all people. Let me see if I can cover all angles briefly. There is need for bulk fiber and a need for quality wood. I believe they are not only compatible, but that foresters and industry must believe this and practice it. There is the puckerbrush forestry of Harold Young which will have a place in providing the bulk fiber the world needs. I have no problem believing the foresters, the engineers and the chemists will solve all the intermediate problems it now may have. As an example, when I first came to work in Maine, S. D. Warren Company took no oak for their paper making. Then they took 10% oak well scattered throughout the load; then 30% well mixed throughout the load, in other words, not entire tiers, and then suddenly you could bring in all the oak you wanted, truckloads and woodlots full of oak. At another period, S. D. Warren took green white pine, but the Brown Company wanted their pine seasoned a year before delivery. As I raced between their paper making plants trying to figure this one out, I began to realize the limitless potential of our forests and our chemists.

But there was also the human element that contributed to the problem - and some of you here may be old enough to remember when pulpwood contracts specifically read "the entire tree and the entire woodlot will be cut into pulpwood. Any trees, or portions of trees, diverted to other products or markets will be cause for cancellation." And "integrated logging" was a dirty word that Bob Dinneen thought up while sitting at his forestry desk.

Some of you may read the Forbes magazine, a financial publication - and all of you know the International Paper Company, the largest paper company in the world. While I have heard they had things going on the past year or so, changes, etc., that are interesting, the June 16, 1976 (1) issue discusses these and other things in more detail. Their new president, Stanford Smith says, "We're in the land resource business" and continues on citing what he says is an industry truism "You get your highest value from using trees as poles, the next highest from lumber, then plywood. Paper is last. Only the residuals are ground into pulp for paper."

Stanford Smith is about my age - not a forester - and became president of I. P. in January 1974 and he is saying now all these nice well known things that I, and many other foresters, were saying years ago, and he's President... and I. P. never even offered me a job scaling pulpwood - Ah, Kismet, thine name is fate.

My point to the above digression is that if we as foresters, we as land managers, continue to ignore the needs of our woodlands for intermediate cultural practices, then we are basically in the bulk fiber production business - the residuals - if you wish, that I. P. President Smith says is last in the line of profit making. And hence the last in the line of profitableness for the small woodland owner who is the provider of a vast amount of our stumpage and is one of our largest landowners. He has to be kept financially viable or else you are going to deal with an ever increasing number of total preservationists.

And the only way he will remain not only financially viable, but interested in continuing in the forest landowning business, is by making it possible for him to grow high quality timber, and intermediate cultural practices are the key to doing this successfully.

And Bob Dinneen, past and present non-entity, and Stanford Smith, now President of the International Paper Company, the largest paper maker in the world, both say this applies to all landowners, big and small.

You have all seen hundreds and thousands of acres cut and left to grow and we may acknowledge they have bulk fiber - but how many have quality wood growing? A few years ago the Forest Management Division of the Maine Forest Service visited the Bartlett Experimental Forest in New Hampshire and saw an excellent hardwood site covered with pin cherry and white birch 35 feet tall and 2-3 inches in d.b.h. The pin cherry was the dominant species and the white birch was hanging on. We discussed why this had not been weeded, a precommercial treatment, and were told that pin cherry being a pioneer species would die out soon and the white birch would take over. I may agree with this, but what of the 15-20 years and money lost by prolonging the time of harvest because the white birch has been held back all this time? On a more personal note, I bought a piece of land in 1948 that had an area that had been blown down by the 1938 hurricane. My reconnaissance showed that the area had an excellent stocking of vigorous white pine along with miscellaneous hardwoods including poplar, pin cherry, grey birch and white birch. I felt that the area was not pressing as as far as working on it immediately compared to other areas. Unfortunately, a constant need for money continued this line of reasoning, as I only very occasionally looked the area over again..... And one day I looked it over and found that less than 5% had white pine and the rest miscellaneous hardwoods, most of low value. It is obvious now that I had my priorities wrong, as at the time very little work would have been necessary to bring the white pine through.

If a person such as myself who is a firm believer in the need for intermediate cultural practices lets himself be diverted so easily, what about all the foresters and forest land managers - and their bosses - who may not really be sold on these practices, and have many pressing problems needing - they believe - immediate attention. You are right - intermediate cultural practices take a far back seat.

On a more optimistic note, I had a 10 acre old field stand of white pine approximately 25-30 years of age in need of thinning and pruning. This I thought had real priority and in 1955 it was thinned for pulpwood and a stumpage return of $1.50 per cord was received. I then personally pruned 100^+ trees per acre to 17 feet. (No wonder I never got to the weeding job mentioned above.) In 1975 a power line had to go through it so we made a study of the results from the pruning, sawing pruned trees and adjacent unpruned trees at a local sawmill. (2) These trees were marked, measured, etc., before the power line clearing commenced. The results were as follows:

Lumber Grade Recovery From Pruned Logs	
Selects	17.3%
#1 and 2C	41.4%
#3 C	31.7%
#4 C	9.6%
#5 C	0.0%
	100.0%

Lumber Grade Recovery From Unpruned Logs	
Selects	1.5%
#1 and 2C	7.8%
#3 C	49.9%
#4 C	40.5%
#5 C	0.3%
	100.0%

Or to put it in other words, 58.7% of the lumber produced from pruned logs was Grade 2 C or better, while only 9.3% of the lumber from unpruned logs was in Grade 2 C or better.

My money pruning investment at the time was 20¢ a tree, or $3.83 per MBF for the pruned log sample. According to the figures, the actual value achieved was equivalent to an interest rate of 17.68%. Carrying it further, the study showed it would have been possible at the time to invest 77¢ per tree and still show an earning rate of 10%, or invest $1.61 per tree and show an earning rate of 6%.

Following me will be Harold Hocker of the University of New Hampshire and Bob Frank of the U.S. Forest Service at Orono to talk on the Research Potential that Silviculture holds, and Ted Tryon of Sewall Company and Oscar Selin of the Georgia-Pacific Corporation to discuss their field experiences. I am sure they will have other examples to offer you from their work in the field.

In 1968 I wrote a Paper on Research Needs for the Cooperative Management Program of the U.S. Forest Service giving my views on this subject. As a farewell gasp - gesture - as I left the lucrative field of forestry last February, I xeroxed it again and sent copies to the U.S. Forest Service with a mild note saying I hoped someone would try reading it.

I was most happy to have an excellent reply (my only one) from Bill Leak, Silviculturist for the USFS at Durham, N. H. who said some things I think are timely and important. (He also says that some of the things I said in 1968 were not complimentary.)

One of his points is that putting together guidelines that are practical and specific enough to be used by practicing foresters is difficult. And I agree with him.

Another major problem is economics. He says many researchers are not heavily oriented in this direction - and I agree - but add that, unfortunately, neither are most field foresters. (Can a cord of wood or a thousand board feet of logs be cut and transported at a profit? That's first grade arithmetic... Can you do a pre-commercial thinning, carry it out at $1.op^n$ for yourself or your company and make a profit? Man, that's forest economics.) Are we knowledgeable in this so all of us, from the bottom to the top of the forestry ladder can use it easily, correctly and saleswise for our companies so they will invest in a forest management program? So they invest in title searches, boundary line work, roads, equipment...... but forest management work? That is a good question.

Another major problem is products. Fortunately, here in New England, and particularly in Maine, we are blessed with many diversified markets and products that possibly even Stanford Smith, IP's president, may not know about from the listing he made. But what I recommend in Maine, may not be valid in Vermont. - However, that is true only at the moment I said it. Given any number of changes - market demands, better roads, better trucks, knowledge of markets and a good salesman-forester - and my statement will not be valid tomorrow. But are we as foresters keeping up with these important points or are we bound to our traditional market places? Another question to ask...do we need quality products, produced by intermediate cultural practices, to be able to afford longer trucking distances? I am sure all of you have heard of raw products being trucked phenomenal distances that a few years ago would have been thought impossible. (Not to mention some years ago shipping Dutch Elm infected logs from Holland to middle America for further manufacture as well as spreading the disease.) Along this line, a few years ago, Blynn Merrill a former Service Forester with the Maine Forest Service resigned to go to work in New Hampshire for a private company. He sold forest products to markets in Maine, trucking tremendous distances, that few in New Hampshire had ever even tried to tap before, and did it successfully.

I believe one of our major needs - and many people are in agreement on this - is to get our forest research and forest economics into practice by our field foresters. I believe this will only be accomplished - if and when there is a persistent, dogged effort by forest supervisors to upgrade and train their foresters through continual educational and training programs. In these programs, the forestry schools and the Society of American Foresters through its sections and chapters, must be involved and lend their time, expertise and facilities.

But most important, this education and training must have the complete support of top company and public management personnel, aiding, pushing and abetting their foresters. It is only by such encouragement that foresters will be successful in bringing their profession to its rightful place that we all believe it should hold.

It will not be easy - it will not be an 8 to 5 job as some new, and possibly some old, foresters believe. But forestry has never been an easy profession.

I believe we have the ability, I believe we have the will, and I believe the country has the need for us to achieve this high professional status to supply it with the goods and services that will be needed in the years ahead.

And I also believe that Intermediate Cultural Practices are important keys to our being able to do this.

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SILVICULTURAL POTENTIAL FOR PRE-COMMERCIAL TREATMENT IN NORTHERN FOREST TYPES[1]

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Abstract

It is proposed that pre-commercial thinning of young northern hardwood, oak, white pine and spruce-fir stands be carried out using appropriate stocking guides to regulate stand density. Thinning should be carried out when stands are between 1" and 2" dbh. Pruning of eastern white pine is recommended, while pruning of spruce and yellow birch seems feasible, markets for the better grades must be present. Application of nitrogen, phosphorous, and potassium fertilizer does not appear to warrant general use at present. More research is required to determine growth response of the various species on different sites to N, P, K application. Present high cost of nitrogen fertilizers appears to be a major limiting factor to their use.

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In the three northern New England states, there are approximately 7.8mm acres of seedling and sapling stands, about 30% of the total commercial forest acreage. (Ferguson and Kingsley, 1972; U.S.D.A., 1973; Kingsley, 1976). I present these statistics to you to point out that there is a significant potential for increased management activity, intensive silviculture if you wish, which can be carried out in existing stands. Stands which, for the most part, represent a minimal investment to date, and will not require such large capital costs as those incurred with artificial regeneration of forest stands. Nature has done the work of regeneration on these young natural stands, and if some silviculture can be applied to them, it can be expected that their value can be enhanced.

The pre-commercial silvicultural practices which will be considered here are the intermediate practices carried out in a stand before a commercial volume of timber can be removed. The practices can be designed to increase either yield or quality of a stand, or both growth and quality of individual trees, and as a result, an increase in financial return at a future date, or they will shorten the time required to produce a final crop, which also represents an increased financial return. Specifically, the practices to be considered are pre-commercial thinning, pruning, and application of fertilizer.

Pre-Commercial Thinning

At the present time, pre-commercial thinning implies a thinning which does not result in the production of a marketable product; however, with the rate at which technological changes are taking place in harvesting and utilization systems, we may be required to revise our concept of whether there is such a practice as a pre-commercial thinning.

Stocking, site, age are factors which determine growth of individual trees in a stand. Age and site for a given stand can be fixed and the effect of stocking on growth can be determined. It is primarily diameter increment which is involved. Chisman and Schumacher (1940) showed that stocking of individual stands can be evaluated by a function where $S = b_1 N + b_2 d + {}^{\Sigma} b_3 \Sigma d^2$ (where N is number stems per acre and d is dbh of individual trees). Trimble (1969) found also that this stand relationship best defined growth of individual trees within a stand when compared to several individual tree measurements. Earlier, Buell (1945) used the relationship to define growth in un-evenaged stands of oak and mixed oak-pine.

Gingrich (1967) using the Chisman-Schumacher relationship and data from Schnur (1937) developed a stocking guide for evenaged mixed oak. Gingrich showed that a single stocking guide could be utilized for a variety of sites and ages; that trees on the better sites enter different stages of growth earlier than did trees on the poorer sites, and as a result, it was position within the stocking guide which separated stands on the better sites from stands on poorer sites and, therefore, it is not necessary to have different guides for different sites. Further, tree diameter reflects the age factor and as a result, a single stocking guide will serve for stands of different ages.

To establish stocking levels, it is necessary to set the upper or full stocking 'A' level and a lower or minimum stocking, 'B' level. If sufficient space for only dominant and some codominant trees is accepted as B level stocking, this level can be used to define the lower limit of stocking of stands to be accepted for management (Figure 1). 'A' level is set by values from fully stocked stands, which are obtained from normal stand tables. The result of this process is the production of a stocking guide which can be used to measure the stocking level of any stand whose species composition matches that of the species for which the guide was developed.

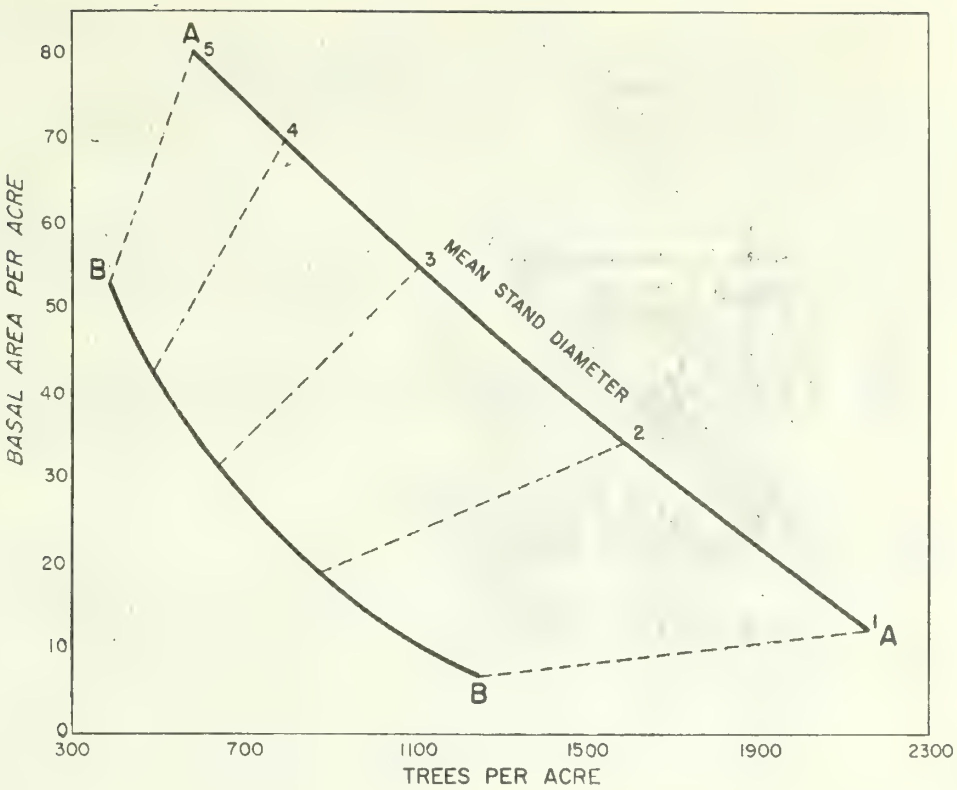


Figure 1.--Stocking guide for even-aged sapling stands of paper birch. From: Solomon, D. L. and W. B. Leak, 1969.

Before a decision can be made whether to treat a stand requires that an estimate of stocking be made. It is important to know, for example, what proportion of a stand is made up of desired stems of desired species, and whether this component of a stand is adequate to utilize the site if the remaining stand, or a part of the remaining stand, is removed. A stocking guide is the primary tool for determining stocking level of a stand. In addition to the oak stocking guide, stocking guides have been developed for paper birch (Marquis, Solomon, and Bjorkbom, 1969); for northern hardwood (Leak, Solomon and Filip, 1969); for spruce-fir (Frank and Bjorkbom, 1973); for white pine (Philbrook, 1971). These guides provide a means for making a decision of which stands to treat in a thinning and which stands require more drastic treatment such as conversion. Note needs to be made of the fact that the minimum mean stand diameter, MSD, for the guide for oak is 3"dbh, spruce-fir 5", and white pine 5".

Using several sources, a compilation of densities was determined for stands with MSD below those given in the stocking guides for northeastern species (Table 1). Number of trees per acre in young stands is an adequate expression of stocking since basal area does not differ a great deal among stands having large

Table 1. Number of acceptable stems per acre required to meet a 5"MSD 'B' line stocking level.

		Northern Hardwoods				
MSD	Paper Birch	All Comm. Species	Intolerant & Intermediate	Spruce and Fir	Oak	White Pine
1	1250	2050	1430	1660	1780	1354
2	890	1390	1040	1340	1154	986
3	650	890	730	1075	780	750
4	490	580	540	850	525	596

differences in number of stems. Note in Figure 1, that for paper birch, a 1" MSD stand with 2000 stems per acre has a basal area of 11 f^2; while a stand with 1250 stems per acre has a basal area of 7 f^2/acre - a difference of only 4 f^2.

As valuable as the stocking guides are, they do not indicate whether a stand after thinning will respond sufficiently to carry the cost of treatment, or how long it will be before another thinning can be made. For this, it is necessary to be able to estimate stand growth with and without treatment, more exactly it is necessary to be able to estimate value increase as a result of treatment.

Murray, Russell, and Barrett (1975) have developed a computer program to estimate stand growth for several species groups utilizing stocking guides and growth equations for each species group. This program, called "MIXUP", estimates growth of white pine, spruce-fir, oak, northern hardwood. The program projects growth of a stand through the stocking guide for each species using stand position before thinning with respect to a fully-stocked condition to estimate mortality. Growth of a stand is established using a stand mortality predictor to determine number of trees and basal area increment with and without thinning.

If a stand is to be thinned, its growth and final condition can be estimated, assuming that the thinned stand has the same growth pattern as an unthinned stand of the same characteristics, and the final volume compared to the volume estimate for the stand if it is not thinned. Marsh and Burgers (1973) conclude that this method for predicting growth of thinned stands is sound; however, the time interval between thinnings should not be carried beyond five years for species in South Africa.

There are two major limitations in this approach to simulation. One is the accuracy of the estimated mortality. To be able to predict volume at some future time requires that mortality of trees of different sizes in the stand be estimated. "MIXUP" can estimate total number of trees which die, between periods, but not mortality on each size class. There is a need to improve the ability to estimate mortality so that future stand structure can be estimated more accurately. It is important to estimate the number of trees which survive in the different diameter classes to be able to estimate stand volume accurately. It is toward this end that research is being directed. Dale (1972) has developed a program for mixed upland oak.

A second limitation in this "MIXUP" simulator is that it will not permit estimates of growth for stands less than 5" MSD. As a result, the program does not meet the need for stands which require pre-commercial treatment.

If stand structure can be set early in the life of a new stand, say in the late seedling-early sampling stage, then the chance of increasing production is increased over that of stands in which treatment is delayed until pole stage or later. Gingrich (1971) showed that young oak stands when thinned at age 10 years, had greater production than stands thinned at 30 years or older or were left unthinned. By shaping structure of young natural stands, it is possible to duplicate some of the early rapid growth which occurs in plantations. Young trees when released are able to expand into the space available and fill out their crowns and extend their roots into the area formerly occupied by competing growth. Young trees have the capacity to make rapid growth and because they have not been suppressed, are able to take immediate advantage of the additional growing space. Quality of growth should be better because the young trees have not been suppressed too long under the domination of less desirable but more vigorous stems.

Dale (1972) suggests that in young oak stands stocking level be reduced to about the 60% level (near the 'B' level) as soon as possible, and that because of differences in stand structure, it is not necessary to adhere specifically to the 60% level, that it may be entirely suitable to reduce stand basal area of young oak by 10-20f^2. Gingrich (1971a) indicated that at age 20, unthinned oak stands would have a basal area/acre of 55-70f^2, and thinned stands would have 35-46f^2/ac. The conclusion that volume production is better with early or heavy thinning agrees with the conclusion of Johann and Dollanschutz (1974) for Norway spruce.

Heavy early thinnings repeated at frequent intervals can result in stands which mature earlier than stands which are kept at moderate stocking levels. Burton and Shoulders (1974) report that a loblolly pine stand which was first heavily thinned at age 9 to 100 trees/acre followed by two more thinnings at age 19, leaving 76 trees/acre, and age 24, leaving 64 trees/acre produced, at age 27, a volume of 11.9Mbf/ac. with a MSD of 14-15 inches; compared to a stand which was thinned every 3 years to 85f^2/ac. which produced 5300 bf/ac. with a MSD of 10 inches. Mann and Lohrey (1974) state that southern pine stands with 5000 or more stems per acre should be mechanically thinned at age 3 years so that there are between 500 and 750 stems per acre. Such a density will not reduce yield and treatment can be carried out at a minimum cost. Wiley and Murray (1974) after a study of pre-commercial thinning in Douglas fir found that the increase in merchantable volume in that species is sufficient to warrant adoption of early thinning as a standard practice on Weyerhaeuser lands.

Not all of the reports of early treatment indicate that the efforts are long lasting or necessarily favorable. Della-Bianca (1975) reported that a release carried out in a 11 year old mixed hardwood stand showed after 10 years that there was a 46% increase in diameter and 38% increase in basal area of released trees, but that there was no significant difference in production for cleaned over uncleaned stands. This brings out the importance in the need to consider the volume units which are used to measure production. If board foot production is the criteria for measuring production, then early thinning to get trees to a 9 inch dbh as soon as possible may show satisfactory results. If cubic foot production is used to measure growth, stand volume differences, due to tree size may not be so large with the result that stands in which partial release is carried out will not be shown to be disadvantaged from released stands.

Thinning Methods

Early release can be accomplished either mechanically or on an individual tree basis at a cost of $25-40 per acre. At the present time, it would appear that stands on better sites should be treated first; that if early release is to be effective on a cost basis, site index of northern hardwood should be greater than 60 feet; eastern white pine 65 feet; oak 70 feet; spruce-fir 46-50 feet. McCauley and Worley (1969) and Webster and Meadows (1971) indicate a need to consider site quality when considering intermediate operations in paper birch and oak stands; on the better oak sites (70-90 ft.), they estimate a rate of return of 7-8% for pre-commercial thinning in oak stands.

Method of treatment will vary with ownership. On private non-industrial land the tendency is for treatment to be applied to individual trees either by chemical or mechanical girdling, or by felling. Various estimates of cost have been made (for example, Ashley, 1975). ACP and FIP per acre rates average around $40/ac. It can be expected that axe girdling with herbicide treatment will require 6-12 man-hours per acre (average 9 hours) - about 1 acre/man day.

On large industrial ownerships and on public lands, treatment may be done with a bulldozer, a drumchopper, or a "thinning machine."

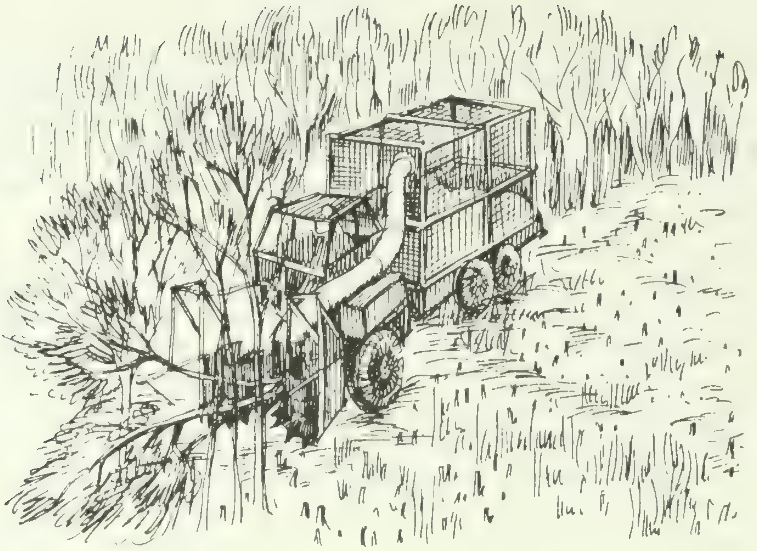
Current practice is to mash down, to chop, to cut strips (Wilton, 1971) or to cut and chip trees at intervals in the stand leaving intervening intact strips. In jack pine, 7 foot chopped strips with 7 foot intervening strips resulted in a 40-50% increase in growth of trees adjoining the strips when there were 12M stems/acre, but there was no improved response in a stand where there were 24M stems/acre (Bella, 1974). In very dense young stands, it is apparently necessary to release trees within the intact strip when mechanical thinning is carried out.

The Pallari Busharvester (Hakkila and Mäkela, 1975) which is being developed in Finland may make it possible to utilize rather than destroy the material when mechanical thinning young stands (Figure 2). Even though the yield per acre from an early harvest may not be self sufficient in cost, a partial return might be sufficient to reduce the present cost of bulldozing which is around $25/acre.

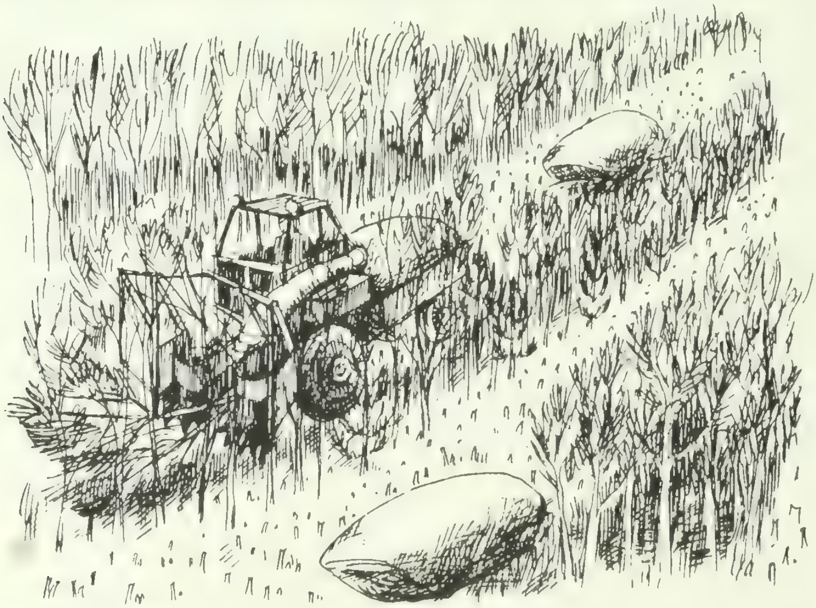
Pruning

If it can be shown that pruning increases grade recovery of lumber in a specific time, then pruning will probably pay off. Hocker (1973) using lumber grade recovery for different tree grades of eastern white pine, showed that it appears quite possible to earn a high rate of return from pruning. The rate of return for a $0.65 pruning cost per tree ranged from 9-14% depending upon estimate of value increase and length of time required for trees to reach the desired 14" dbh.

McCoy (1976) in a more thorough study of pruning eastern white pine, showed that trees having the butt log (12 ft.) which graded II or III had the best potential for retuning relatively high rates of return; that the rate of return begins to decline for investment periods beyond 30 years for Grade III trees and age 40 for Grade II trees (Table 2). It would appear that pruning to a height above 12 feet results in a reduction in rate of return if the grade of the second 12 foot log is the same as



a. Felling and chipping in clear-cutting of small-sized hardwood. Recovery of chips into the container of the bush-harvester.



b. Felling and chipping in corridor thinning of a young pine plantation.

Figure 2. Illustration of the Pallari Busharvester (from Hakkila and Mäkela, 1975)

Table 2.--Best combination for pruning white pine trees based on tree grade, pruning height, and investment period (taken from McCoy, 1976).

Years from pruning	Grade 12' butt log	ROR pruning 0-9	Grades 2'd 12' log	ROR pruning 0-13'	Grade 2'nd 12' log	ROR pruning 0-17'
		%				
20 year	III	9.16	III	8.62	III	7.78
30	II	7.94	II	6.99	II	6.62
			III	8.43	III	7.78
40	II	8.28	II	8.00	II	7.74
			III	8.37	III	7.77
50	II	7.78	II	7.54	II	6.93
			III	7.76	III	7.25
60	II	7.20	II	7.02	II	6.52
			III	7.14	III	6.70

the grade of the first log; e.g. Grade II - Grade II. If the grade of the second 12 foot log is lower than the first 12 foot log, i.e. Grade II - Grade III, then the rate of return from pruning increases for trees pruned to 13 or 17 feet. The study showed that at no time does rate of return for Grade I 12 foot butt logs compare with pruning Grade II or Grade III trees. Apparently, it does not pay to prune Grade I trees unless the alternate rate of return is 6% or less. The study assumed a $50 per day cost of pruning and an assumed diameter growth of 0.3 inches for pruned trees.

It would appear that satisfactory rates of return could be obtained for yellow birch if there is a good price difference between lumber grades. Whether it pays to prune spruce, I cannot say. This would depend on the value difference for the different grades. Berry (1964) did find that it required twice as much time to prune white spruce (9 minutes to 17 feet) as it did to prune white pine to the same height; however, he did indicate that where a market differential existed for pruned spruce, that pruning did seem feasible.

The results of the white pine analyses do show that it is important for trees once pruned to maintain a rapid diameter growth rate. At least 0.3 inch annual diameter increase is required; if diameter growth is less, rate of return is less.

Fertilization

Here the picture is blurred. Reports of significantly increased tree growth in other regions after application of nitrogen and/or phosphorus are accepted. When we look at results for local studies, the growth responses are not always encouraging. Hendrickson (1976) showed that average annual volume growth of white pine treated with 400 lbs./ac. of N; 50 lb./ac. of P; 100 lbs./ac. of K was 10% over 5 years compared to 7% for control. There was much variation in the data and the increase in growth was significant only at the 5% level. Safford and Filip (1974) reported that fertilizing 4 years after clearcutting a northern hardwood stand stimulated growth of pin cherry so much that growth of the more valuable stems in the stand was suppressed. Van Althen (1973) recommended that fertilizer not be used at the time of regeneration in northern hardwoods. A southern report (N. C. State, 1976) indicated that there was no response of naturally reproduced hardwood stands to N. and P. applications.

Leaf (1970) summarized the results of their studies with potassium on conifers growing on a Hinckley soil in New York. Red and white pine and red and white spruce showed responses to applications of K, while Scots pine did not show a response. The response of red pine was best at 110 to 165 Kg/h (98-147 lbs./ac.). A response to K was reported for pine growing on wind blown soils in Europe (Bruning and Krolikowski, 1973). Stratton, Safford and Struchtemeyer (1960) note that white pine responded to K 100 lbs./ac. on a droughty site.

Gagnon, Conway and Swan (1976) state that for white spruce additions of other elements as well as nitrogen seemed to produce little added response in closed stands. They did find that addition of potassium as potassium sulphate at rates of 100 to 200 lbs./ac. resulted in an increased wood value in 1975 of $18.00 for a $2.36 cost (an ROR of approximately 16%). They indicate the 1975 nitrogen costs have reached a level where it is not feasible to consider using urea fertilizer.

Weetman (1975) reported that black spruce responded to both thinning and fertilizer application. Best response was to 50% reduction in basal area and application of 400 lb./ac. N (29.7f^3/ac./yr.) but this was not different from 100 lb./ac. of N (29.0f^3/ac./yr.). This would compare to an increase in growth rate of 50f^3/ac./yr. for white pine receiving 400 lb./ac. N (Hendrickson, 1976).

Weetman *et al* (1974) reported on a number of studies involving black and red spruce and jack pine where growth increased 7-24 f^3/ac. for black spruce, and 20-22 f^3/ac. for jack pine after application of 100 to 400 lb. N/ac. Best response for black spruce again as the 50% thinning and application of 400 lb. N/ac. where growth response of 37.8 f^3/ac./yr. was noted.

Although the responses to N fertilizer appear significant, growth increases reported to date do not appear to warrant a great amount of enthusiasm when they are considered in a cost/unit growth context. For example, if the response of white pine to an application of 400 lb./ac. of N. is considered, fertilizer would cost $78.80/ac. (spring 1976 cost of N as NH_4NO_3 = $0.187/lb.) for the N. Over a 20-year period at a 6% ROR, this cost would increase to $239.89. If stumpage is worth $0.176/cu. ft., a growth response of 1363f^3 in 20 years (PAI = 68f^3) would be required to return the cost of fertilizer alone. Using the estimate of Cromm (1974) for determining delivery and application costs, and adding these costs to the cost of N reduces the ROR to 4.4% over 20 years, assuming growth increase is sustained for the 20-year period.

It is quite important when applying fertilizer that growth increase be placed on the larger trees in the stand (Moller, 1971); that none be wasted on small unmerchantable trees or on understory vegetation. Therefore, stands to receive fertilizer should be ones where there is an adequate stocking of commercially valuable trees.

Although site quality has not been directly related to fertilizer application in the Northeast, Handley and Pienaar (1972) note that growth response of Douglas fir to N application increased with increase in site index and with application of N up to 300 lb./ac. Perhaps the lack of a relationship to site quality and N application in the Northeast is the result of site quality not having been measured directly in each study. A site quality growth response can be implied on excessively drained soils (low site) where responses to K are recorded. Responses to N have been recorded on the well-drained to somewhat poorly-drained (med. to good) sites. Pritchett and Gooding (1974) indicate that established stands of slash pine on poor to somewhat poorly-drained soils may need applications of N and P, or N-P-K; on moderately well-drained soils stands may require application of N; on excessively-drained soils stands may require N only.

Summary

It is important when contemplating any intermediate silvicultural treatment that consideration be given to stocking and to site quality. Stocking guides are available for most of our commercial tree species. Value increase per unit of production should be the criteria used to measure response to treatment. Before a treatment can be considered for operational use, unit cost of treatment should result in a marginal return sufficient to pay the cost of treatment. It would seem that when research results are reported, response would be best measured as periodic annual increment, in cubic foot/acre/year. By doing this, it is possible to make estimates of marginal value increase.

Pre-commercial thinnings should be made as early as possible after stand establishment, probably when stand MSD is between 1" and 2". Thinnings seem feasible where stand composition can be altered so that the more valuable species are favored on the better sites, and where stocking levels for young stands exceed that required to meet the 'B' line level at 5" MSD. Pruning can be considered for white pine, white spruce and yellow birch where there is a premium for clear wood.

More research is required to determine where fertilizer application has a place in the Northeastern forest. We also need to improve computer simulation programs to permit more precise estimates of growth and estimates of returns for intermediate practices, primarily from different thinning methods. Eventually, computer programs should be developed to take into account pruning, fertilization, and use of genetically improved trees.

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FIELD EXPERIENCE SILVICULTURAL CLEANING PROJECT IN YOUNG SPRUCE AND FIR STANDS IN CENTRAL NOVA SCOTIA

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Abstract

Silvicultural cleaning production varied from .15 to .34 acres per man day using light weight chain saws in young Spruce and Fir stands in Central Nova Scotia.

Direct labor and saw costs, in cleaning young softwood stands in Nova Scotia, can be expected to range generally from $55.00 to $90.00 per acre, depending on crew experience, stand density, and equipment used.

Many of you are aware that the James W. Sewall Company, in 1970, opened an affiliated Canadian office in Truro, Nova Scotia, and in 1974 purchased, renovated, and moved into a former military building in the new Debert Air Industrial Park in Debert, Nova Scotia, being on land of the former Canadian Forces army camp, commonly referred to as Camp Debert. We are now located about ten miles West of Truro.

You may possibly be asking yourselves how we became involved in a project of this nature. As you can appreciate, operating and expanding a new based forestry and surveying consulting business offers headaches relative to maintaining experienced and reliable staff through periods, where business volume fluctuates considerably from one month to the next. In an attempt to keep trained cruisers and instrument men on our payroll during slack times, we reached an agreement with the Nova Scotia Department of Lands and Forests, in which we contracted to silviculturally treat approximately 50 acres of young Spruce and Fir thickets by 'cleaning', referred to as "spacing" by some. This agreement contained no stringent time constraints, allowing us to work on the project while not engaged in our normal consulting work, and most importantly enabled us to keep our experienced men for when we needed them for cruising and surveying.

Leading into a more in-depth discussion on our field experience, I feel it appropriate to take the time to give you a little background regarding silviculture programs in the Province, which will serve as a partial explanation for the high-cost, long term investments having been and presently being invested in softwood land in Nova Scotia.

In 1965 and 1966 the Nova Scotia Department of Lands and Forests initiated a stand improvement program, and since that time have silviculturally treated roughly 50,000 acres of which some 10,000 acres have been "cleaned" or "spaced". In 1975 they "cleaned" 767 acres and have projected completing the same on 1000 in 1976.

In 1958, the Nova Scotia Pulp Company, now called Nova Scotia Forest Industries, with a pulp and newsprint mill in Point Tupper, Nova Scotia, entered an agreement with the Province of Nova Scotia and agreed to build a pulp mill in Eastern Nova Scotia, sell as much of their product on the local market as possible, and prepare within five years of the start of the mill a forest management plan for the lands from which they were to receive their wood. In return the Province gave them cutting rights on all Crown Lands in the seven Eastern counties of Nova Scotia.

N.S.F.I.'s forest management plan is called "Silviculture" and is directed toward producing harvestable pulpwood volumes in treated stands within 45 years as opposed to 60 years in untreated stands. This program is largely funded through an agreement with the Province by which Nova Scotia Forest Industries pays the Province $2.75 per cord of softwood cut from the lands, of which $1.75 is channeled into a silviculture fund and is spent on the silvicultural improvement of the lands.

Since 1971, Nova Scotia Forest Industries have silviculturally treated an estimated 30,000 acres of leased Crown Land of which about 9,000± acres have been "cleaned". They plan on "cleaning" about 3,500 acres this year.

Also; a federal-provincial agreement under the Agricultural and Rural Development Act (ARDA III) has terminated this past March (1976) and a similar agreement, now being negotiated, hopefully will be in effect in the near future. The new program is to be called the General Development Agreement (GDA) and supposedly is to offer private land forestry assistance similar to the previous (ARDA III) program. Presently, while only an interim situation, there is no forestry assistance to private land owners in Nova Scotia other than windfall recovery assistance.

To give you an appreciation of the availability of government monies I want to comment briefly on the mentioned (ARDA III) program. I realize I'm getting away from the subject of interest but we must recognize and realize the role these government assistance programs have played in not only silviculture but other areas of forest management as well.

Anyone owning forest land in Nova Scotia under the past (ARDA III) program, could apply for government financial assistance in the following areas of forestry. In addition to this financial assistance, the landowner is provided professional and technical forestry guidance from the Provincial staff.

I. Woodland Road Construction:

Offered assistance up to 60% of bulldozing and grading costs to a maximum of $900.00 per mile. Assistance of $1.75 per cubic yard of gravel to a maximum of 800 cubic yards per mile. Maximum assistance would be $3,300.00 per mile.

II. Boundary Lines:

Offered assistance at a rate of 60% of the survey costs up to a maximum of $300.00 per mile of boundary line cut and surveyed.

III. Silviculture:

a. Site preparation - Up to $25.00 per acre	
b. Forest planting	
Open root stock	Up to $30.00/M trees
Container stock	Up to $20.00/M trees
c. Acquisition of planting stock	
Open root stock	
Nursery	Up to $40.00/M trees
Wildings	Up to $40.00/M trees
Container stock	Up to $20.00/M trees
d. Cleaning	
Long term	$50.00/acre
Short term	$40.00/acre
e. Thinning	Up to $30.00/acre
f. Pruning	Up to $15.00/acre

Many private land owners recognized full advantage of the road and boundary assistance but response to the silviculture assistance was less than originally hoped for.

At this point I should clear up one point regarding forestry terminology and explain that in Nova Scotia the term "cleanings" is used to describe "weedings" as well. Many treated areas, according to definition, are comprised of "cleanings" and or "weedings". For the benefit of those of us who studied Silviculture decades ago, Smith defines a "cleaning" as: "A cutting made in a stand, not past the sapling stage, in order to free the best trees from undesirable individuals of the same age, which overtop them or are likely to do so". He defines "weeding" as: "A term that denotes the removal of all plants competing with the crop species, regardless of whether their crowns are above, beside, or below those of the desirable trees". While we have used the term "cleaning", we recognize that the area we treated was for the most part "weeded". Michaud, with the Nova Scotia Department of Lands and Forest states: "The cleaning operation is one in which the stem number per acre of a desired species, generally of young stands (i.e. six to 12 feet high, 15 to 20 years old) is reduced to a number more closely approaching that of a mature stand".

Some advantages to "cleaning" and basic concepts we've all been exposed to over the years are:

a. Shorter rotations through increased growth rates by concentrating growth potential on fewer stems per unit area.

b. Reduced harvesting costs through production of larger future crop trees of more uniform size.

c. Species composition regulation.

d. Longer growing season effect through exposing young stands to sunlight penetration.

e. Promotion of well formed crowns and root systems.

Many softwood stands in Nova Scotia, between 12 and 20 years of age support between 10,000 and 50,000 stems per acre. Opinions are that at this age, stand density should not exceed 1000 stems per acre. Studies in Nova Scotia, New Brunswick, and New Foundland indicate that by opening dense stands from 10-20 years old to a spacing of seven to eight feet (700-900 trees/acre) will reduce rotations by as much as one third. Nova Scotia Department of Lands and Forests personnel suggest that a good site with a stand at age 15 and spaced to 700 trees per acre may average a cord per acre per year over the length of the rotation, which may be in the order of 45 years.

Our project called for the "cleaning" of some 50 acres of Spruce and Balsam Fir saplings from an estimated 10,000 to 20,000 stems per acre to an approximate 8-foot x 8-foot spacing or about 680 stems per acre. Seventy-five percent of the stems were Balsam Fir, 24% Red Spruce, and 1% Hardwoods. Heights varied from 4 to 14 feet with average height of eight feet. We spaced, changing the stand composition to as heavy a component of Spruce as possible, achieving a residual stand of approximately 60%-70% Spruce.

(The technical aspects of the basic "cleaning" operation will be presented in a slide presentation in a few minutes.)

We started with a crew of six cutters and a general foreman, the foreman reporting to our forester in charge. The foreman's responsibilities were to lay out and assign segmented working areas to each cutter, to keep records regarding each cutter's weekly production, and to maintain quality control.

In laying out these working compartments, he used a device called a "topo-chain", (See picture) which lays down a fine string, simultaneously giving a reading of the distance laid off. This device enabled the foreman to lay out and measure the working areas unassisted. His records simply consisted of a general map illustrating the location and acreage of each compartment plus a weekly listing of completed acres per cutter. The foreman inspected the works daily and periodically with Lands and Forests personnel, carried out a detailed quality control inspection. During this inspection they measured 1/50th acre plots as a check on residual spacing.

Cutters worked in only the areas assigned, thus keeping out of each others' way, yet being close enough to render assistance should someone get hurt. Fortunately we experienced no bad accidents other than one or two slight nicks with the saws. I might add that operating the type of light weight chain saw that we did, or any other type chain saw for that matter, can be very dangerous in these softwood thickets. Our men were outfitted with safety pants, boots, gloves, safety glasses, ear protection, and hard hats. Also kept on hand were first aid supplies and fire fighting gear. Not so dangerous are the more expensive brush saws, which cost over twice the price of a light weight chain saw but by some are considered more productive for this work. Nova Scotia Forest Industries claims excellent success with the Swedish brush saws called "Husqvarna". (See picture)

All spacing was left to the discretion of the cutters, followed by the previously mentioned inspections by the foreman. They did an excellent job of maintaining a residual stand of the desired number of stems per acre and likewise the overall quality of their work was outstanding. Their instructions were to cut all trees low and below the live green portions of the crowns, thus discouraging the development of new trees from lateral shoots. They were additionally required to fell medium sized hardwoods, large dead stubs and to girdle the larger hardwoods.

Extreme summer heat, flies, hornets and mostly the inexperience of our crew, resulted in a much lower than expected level of production. Their production was .15 acres per man day. We previously, through discussions with Lands and Forests personnel, anticipated a man could "clean" about .40 acres per day. In all fairness, our crew's production included an orientation process. After allowing adequate time and giving the crew the full benefit of the doubt, we realized we were in trouble at this rate of production and subsequently curtailed the project until such time as we could come up with a solution yielding production hopefully of the magnitude of .40 acres per man day.

We were paying the men $70.00 per acre while Lands and Forests, at that time, were paying their crews on a prorated price, proportional to stocking per working area. That is, they paid $70.00 per acre for the most densely stocked areas and considerably less for lesser stocked stands. We paid $70.00 per acre across the board, as a partial recognition of our crews' inexperience.

Because of our unusual working arrangement, we were required by law, to make up the difference if the cutter's piece rate amounted to less than minimum wage. I'm not suggesting that these men were lazy but perhaps that they were smart enough to realize their inexperience and desire would not allow them to earn much over the minimum wage, regardless of their expended effort. In any event, we were temporarily out of the "cleaning business", and our "cleaning" project was 'in the red'.

Our forester in charge, seeking advice, spent an interesting afternoon with Oscar Selin, whose advice was for us to investigate the possibility of using Marden Choppers or similar equipment, for creating regularly spaced, cleared corridors throughout the area, and hand clearing between these corridors. We located the equipment but were denied permission to use by Lands and Forests, until they had evaluated the systems' effectiveness. Their main concern, being the percentage of trees in and on the edge of the corridor that would not be totally killed, thus regaining stature and competing with residual crop trees. This corridor concept makes real sense to us and I believe warrants further investigation in Spruce and Fir thicket spacing.

We additionally investigated the possibility of recovering part of our costs by marketing Christmas trees from the area; this to be integrated with the normal "cleaning" process. We were again denied this option as this was in contradiction with Lands and Forests policy regarding Christmas tree production on Crown Land. Admittedly, in dense softwood thickets many trees are unacceptable as Christmas trees, but many of the interspersed, less densely stocked areas will yield Christmas trees of some standard.

Shortly thereafter, we were approached by four woodsmen, who had just come off powerline right of way clearing, needed work, and were willing to give this a try. After looking the area over, they figured they could earn sufficient money. To avoid the previous situation we were in, we subcontracted the remaining acreage at $90.00 per acre. This crew averaged .34 acres per man day on a completed 15 acres. However, because they were discontent with the work and our supervision and transportation costs still held us over the break-even point, both parties agreed to end the project.

Those of you who ever asked a nurseryman the cost of raising 1,000 seedlings found that comparing his figure to another nurseryman's was like comparing apples to oranges. Not that they're not good figures, but it seems each nursery figures this a little differently. I'm sure the same situation prevails when you go to find out what it costs to "clean" an acre.

In our situation, we got down to where our supervision, transportation, and direct labor was costing us about $142.00 per acre. We were realizing a mark-up on our supervision costs only. Our direct labor cost at this level was $90.00 per acre.

The Department of Lands and Forests cleaned 767 acres last year for $86.93 per acre. This includes a foreman, without the time of the supervising forester being included.

Most impressive are Nova Scotia Forest Industries' figures. They averaged .75 acres per man day on 1,000 acres, with chain saws, and .96 acres per man day on 1,500 acres, with the brush saws. They are projecting their direct labor and saw costs to be in the order of $55.00 per acre for this year. This does not include a field foreman or salaried supervision and planning.

As a closing comment, the number of stems per acre dictates, to a large degree, production rates and should be ascertained by several classes. Good sites that have not been densely stocked by natural regeneration, warrant consideration when selecting areas in which to practice "cleaning".

This talk is supposed to be on our "field experience" and an "experience" it was. What we lost in dollars we charged to "experience".

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INDICATIONS OF SILVICULTURAL POTENTIAL FROM LONG-TERM EXPERIMENTS IN SPRUCE-FIR TYPES

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Abstract

Data collected since the 1950s from commercial treatments on more than 400 acres in the Penobscot Experimental Forest in Maine indicate a high mortality rate of 520 percent of net growth in the woodland preserve where timber is not harvested, a low mortality rate of 16 percent of net growth under the selection system. As the intensity of silvicultural treatment increased, periodic net annual growth increased from 10 cubic feet per acre (0.7 m^3/ha) in the woodland preserve to 56 cubic feet per acre (3.9 m^3/ha) under the selection system.

THE KEY to more productive forests is stand-improvement to replace untended and undertended stands with cultured stands containing fast-growing high-quality trees of favored species. Few are the acres that cannot be improved by ridding them of excessive trees, poor-risk trees, low-quality trees, or trees of inferior species. A rigid scheduling of intermediate cultural operations, preferably in conjunction with periodic thinnings or harvests, will accomplish this and enable the land to produce yields at capacity.

COMMERCIAL VERSUS PRECOMMERCIAL TREATMENTS

Simply stated, a cultural treatment that over time transfers at a profit the growth from undesirable trees to trees that will be removed either as crop trees or in subsequent thinnings is logically a commercial treatment. In this respect intensive culture in stands of trees is not unlike agronomy applied to other crops.

Dunfield (1974) stated that "precommercial thinning may be defined as a silvicultural method to eliminate a certain percentage of trees from a forest stand in order to increase the growing space and growth of the residual trees. The trees destroyed are usually of no commercial value, although collectively they contain a substantial volume of wood fiber."

Berg (1970) defined this in a more profound economic sense. He stated that, regardless of whether or not a thinning operation pays for itself in part or all, it must be considered a precommercial operation unless an immediate economic profit is returned. Worthington and Staebler (1961) were less restrictive. They maintained that, if an operation pays for itself, profit not withstanding, it is a commercial treatment.

Fully realizing that the terms precommercial treatment, noncommercial treatment, and commercial treatment are rapidly becoming archaic because of the more complete utilization of forest biomass, I shall make perhaps one of the last attempts to define the latter--commercial treatment, the subject under discussion. I define this intermediate cultural practice as follows:

> An operation involving the removal from a forest stand of trees primarily of merchantable size and of marketable species in a quantity sufficient to at least equal the cost of the operation and having one or more of the following purposes:

- To reduce stand density in order to increase the growing space and growth of residual trees and new regeneration.

- To reduce trees in diameter classes with excessive numbers of trees.

- To reduce the number of poor-risk trees.

- To reduce the number of trees of low species priority.

The treatment may also include the removal of both nonmerchantable-size trees and merchantable-size trees nonmarketable because of quantity, quality, or species. I have chosen to exclude from my definition pruning, the application of fertilizer, and land-drainage techniques.

CONSTRAINTS AND SILVICULTURAL CONSIDERATIONS

The minimum amount of marketable material necessary for an economic or profitable operation depends on many variables. It probably ranges between 250 cubic feet per acre and 750 cubic feet per acre (17.5 m^3/ha and 52.5 m^3/ha) in spruce-fir types. Among the important variables are species, quality, product, logging conditions including spatial distribution of trees to be harvested, skidding distance, and proximity to mill.

A commercial treatment in a developing even-age stand begins as soon as the treatment is financially self-sustaining. Both in even-age stands and in uneven-age stands, the interval between operations is such that wood losses due to mortality are minimized. This is best accomplished with relatively short periods of time between stand entries. Operating intervals of 10 to 15 years are well suited for this objective.

The amount of growing stock removed during a commercial treatment should not exceed 50 percent, and it can be as low as 10 percent on sites where the danger of excessive wind damage is apparent (Frank and Bjorkbom 1973). A second constraint on the amount of growing stock to remove involves stands not adequately stocked. These stands should be replenished promptly by adding to the growing stock an amount equivalent to a portion of each periodic increment until an acceptable stocking level is reached.

COMMERCIAL TREATMENTS IN SPRUCE-FIR TYPES --SOME EARLY EXPERIMENTAL RESULTS

Extremely varied site and stand conditions in spruce-fir types, coupled with existing market conditions, strongly suggest that silvicultural practices are never uniformly applicable (Westveld 1930). Or, there is not a "best" silvicultural system for all lands all of the time.

History and Scope

An example of various silvicultural systems and management methods applied to formerly unmanaged stands is available. Work was initiated during the 1950s and trends are developing after less than 20 years of treatment. Treatments include three intensities of the selection system, two intensities of the shelterwood system, two intensities of the diameter-limit method, one example of unregulated harvesting by the commercial clearcutting method, and a woodland preserve where harvesting is not allowed. All treatments with the exception of the woodland preserve are replicated twice. Treatment descriptions are outlined in the Appendix.

Data are reported according to availability. For instance, no data are being reported for the two-stage shelterwood treatment because the final harvest in one replication occurred less than 2 years ago. Original regeneration data were not recorded for any treatment, and second-measurement data are not yet available for the diameter-limit treatments.

The Study Area

Data are being collected in the Penobscot Experimental Forest, just 2 miles southeast of Orono, on more than 400 acres (162 ha) of spruce-fir types. Before being placed under management, these stands supported substantial amounts of hemlock and associated hardwoods. Some stands still do. The reason for these admixtures is that the Forest is located in the transition belt between the transition/hardwoods white pine/hemlock and the spruce-fir/northern hardwoods forest types as described by Westveld et al. (1956).

Sites within the study vary from areas of impeded drainage where red spruce (Picea rubens Sarg.), white spruce (P. glauca (Moench) Voss) and balsam fir (Abies balsamea (L.) Mill.) predominate, with northern white cedar (Thuja occidentalis L.) and red maple (Acer rubrum L.) as associates. On moderately well-drained locations, eastern hemlock (Tsuga canadensis (L.) Carr.) is a strong contender for site occupancy, along with occasional paper birch (Betula papyrifera Marsh.), eastern white pine (Pinus strobus L.), and red maple. A scattering of several other species is also present.

Commercial treatments being applied vary in intensity. Volumes removed in separate operations range between 300 and 1,250 cubic feet per acre (21.0 m^3/ha and 87.5 m^3/ha).

Except for the earliest timber-stand-improvement operations, the removal of undesirable nonmerchantable trees has been an integral part of each periodic harvest. The selection, three-stage shelterwood, and flexible diameter-limit treatments receive varying degrees of timber-stand-improvement: the 5-year and the 10-year interval selection treatments are the most intensive. In the latter two treatments, the TSI effort is extended to include trees down to the 1-inch diameter class. The fixed-diameter-limit and unregulated harvesting treatments receive no timber-stand-improvement work. And, in the woodland preserve, no cutting or harvesting of any kind is allowed.

Growth Response and Mortality

Net annual growth of natural softwood stands that have had a minimum of past silvicultural treatment is reported by Safford (1968) to be just under 51 cubic feet per acre (3.6 m^3/ha).

With less than 20 years of intensive culture, our selection treatments average 56 cubic feet per acre (3.9 m^3/ha) per year and range from 51 to 59 cubic feet per acre (3.6 m^3/ha to 4.1 m^3/ha).

There is virtually no difference between the two diameter-limit treatments where net annual growth averages 53 cubic feet per acre (3.7 m^3/ha).

A pronounced reduction in growth is noted for the unregulated harvesting treatment when compared with both the selection and diameter-limit treatments. In this treatment, commercial clearcutting left the stand with only 58 square feet per acre (13.3 m^3/ha) of basal area in merchantable-size trees. As stocking becomes reestablished, growth increases and averages 36 cubic feet per acre (2.5 m^3/ha) per year for the treatment period. Growth during the initial measurement period was only 29 cubic feet per acre (2.0 m^3/ha) per year; during the most recent measurement period, 43 cubic feet per acre (3.0 m^3/ha) per year.

Periodic net annual growth is only 10 cubic feet per acre (0.7 m^3/ha) in the woodland preserve area. With no timber harvesting by man, natural mortality is averaging 52 cubic feet per acre (3.6 m^3/ha) per year. Expressed as a percentage of net growth, mortality is 520 percent in this treatment compared to 42 percent or 15 cubic feet per acre (1.0 m^3/ha) per year in the unregulated harvest treatment.

Annual mortality ranged from 10 cubic feet per acre to 13 cubic feet per acre (0.7 m^3/ha to 0.9 m^3/ha) in the diameter-limit treatments. This is 22 percent of net growth.

Corresponding figures for the more intensive selection-system treatments range from 6 cubic feet per acre to 13 cubic feet per acre (0.4 to 0.9 m^3/ha) or 16 percent of net growth.

These results are similar to the results reported by Snow (1938). He reported that over a 29-year period average annual mortality for an unthinned stand was 49 cubic feet per acre (3.4 m^3/ha). In a thinned stand losses averaged 11 cubic feet per acre (0.8 m^3/ha).

Stand Quality

The reduction in number of cull trees in a stand is a major goal in intensive forest management operations. And the more frequent a stand entry is made, the more rapid and enduring is the reduction.

Intervals of 20 years and longer allow for the continual development of undesirable growing stock. Short intervals--about 10 years--are most efficient in eliminating cull trees and other poor-risk trees that are likely to develop into cull trees (fig. 1).

Cull trees have been practically eliminated from stands being managed under intensive selection silviculture. Cull-tree volume is only 0.2 percent in the 5-year-interval treatment where four combined harvests and timber-stand-improvement operations have already been made. The 10-year-interval treatment shows a corresponding reduction in cull trees to 2.4 percent of total volume after two combined operations.

The only obvious increases in cull-tree representation occurred in the two treatments not subject to stand improvement work--the fixed-diameter-limit and unregulated harvesting treatments.

The reduction in cull-tree representation in the woodland preserve is attributed to the high mortality rate.

Species Composition Changes

An attempt to alter species composition is best described by the cliché, "It is easier said than done!" The only exception is artificial regeneration. Even with this method, invasion of the planting site by formerly undesirable species or by successional species usually requires cultural measures to insure the ultimate dominance of the planted stock.

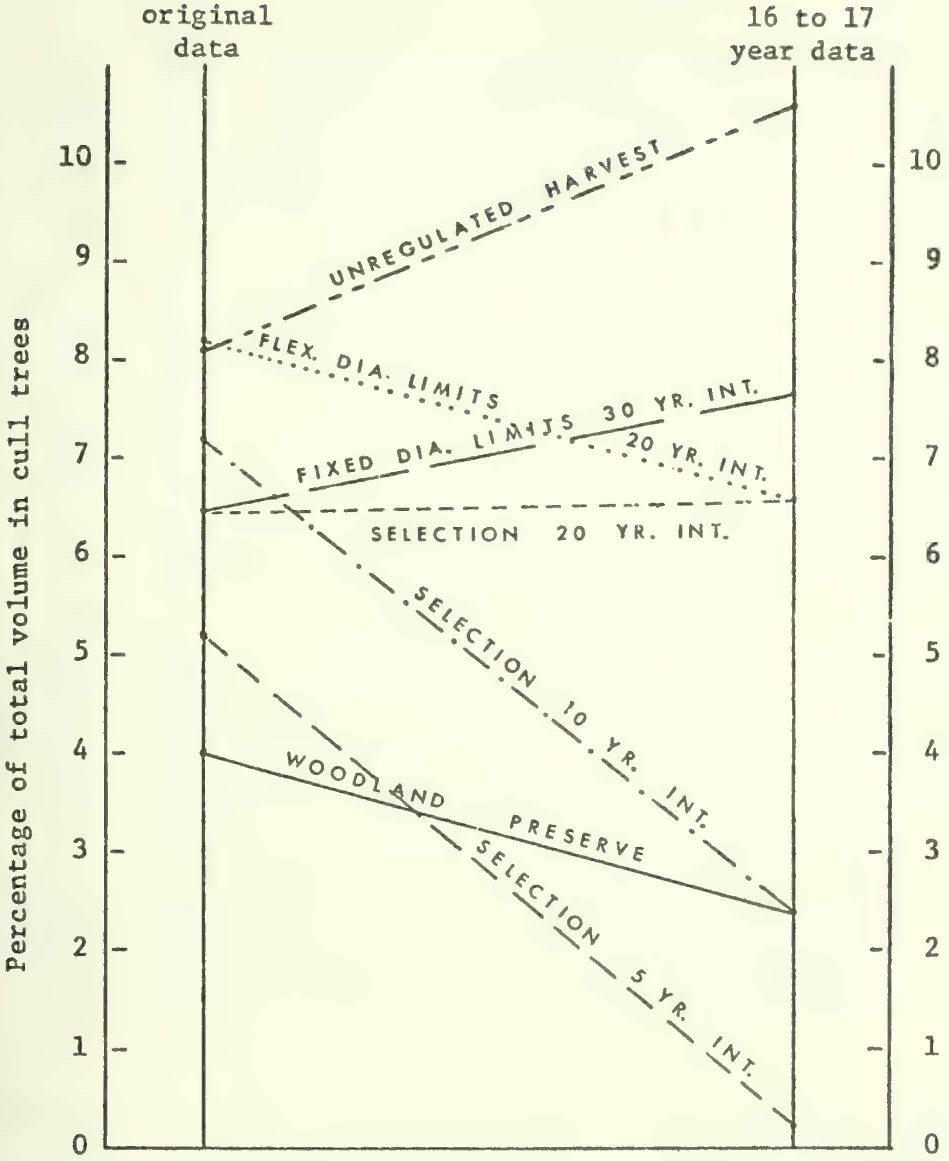


Figure 1.--Changes in stand quality by treatment, all species combined.

When natural regeneration methods are relied upon, compositional changes take place more rapidly under even-age management than under uneven-age management. An example is the shelterwood system.

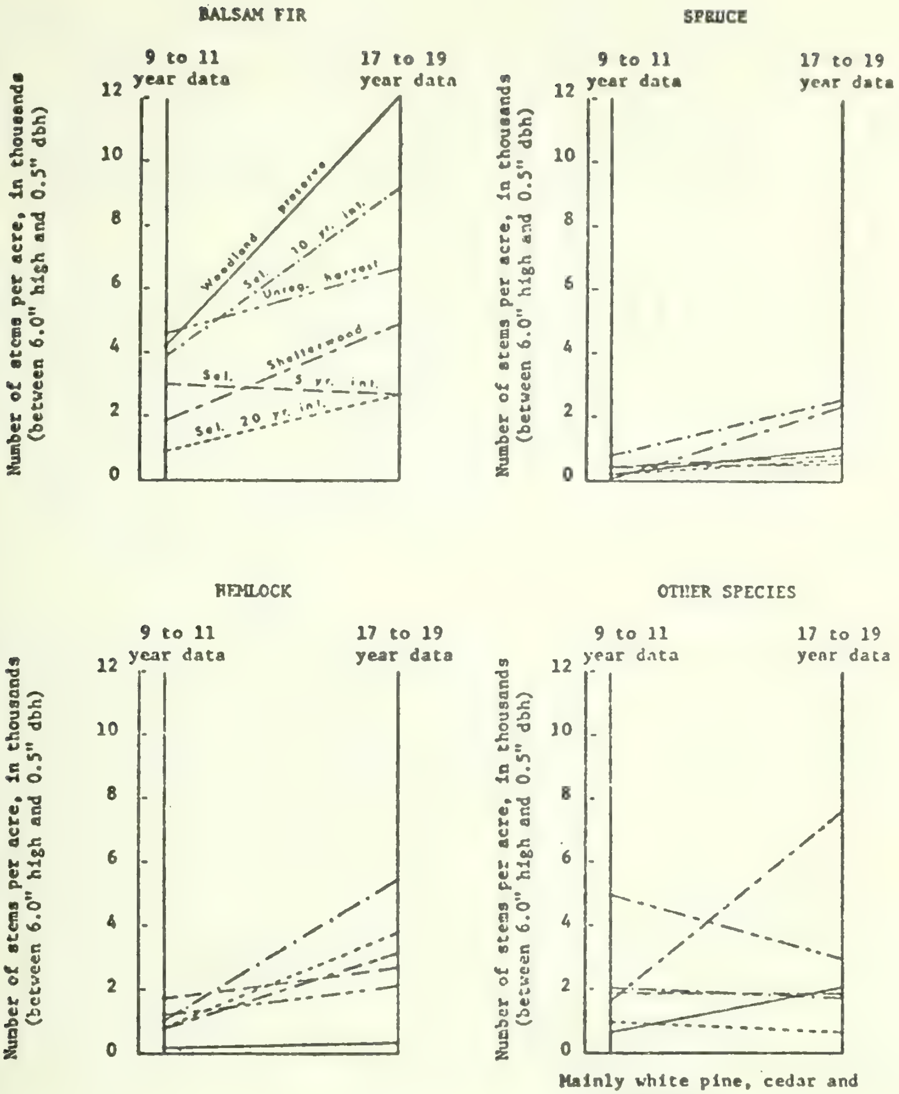
Composition changes in regeneration.--All treatments show increases in numbers of balsam fir seedlings except for the selection-system treatment managed on a 5-year operating interval, where there is a slight decrease (fig. 2). The reason for this is not clear, although the frequency of stand entry with resultant logging damage may be a factor.

Fir seedlings currently range in number from fewer than 3,000 per acre (7,400/ha) in two of the three selection treatments to just over 12,000 per acre (29,600/ha) in the woodland preserve. Continuous dense overstory cover in the woodland preserve, gradually tempered here and there by mortality, plus an almost complete lack of site disturbance, has maintained site conditions suitable for fir germination and establishment but less hospitable to most other species.

Initial counts of spruce were all below 1,000 seedlings per acre (2,500/ha). However, the shelterwood-system treatment, where spruce was favored during the regeneration period, registered a 24-fold increase in spruce seedlings--from 100 to 2,400 per acre (250/ha to 5,900/ha). All other treatments registered gains, but the magnitude of the increases is much less.

The responds to the various treatments by hemlock seedlings is not unlike the response noted for spruce, particularly red spruce. This is because the environmental conditions necessary for their establishment, shade, and adequate moisture are very similar (Fowells 1965).

The reaction of the intolerant species to treatment is more predictable. Hardwoods and white pine show dramatic gains in the shelterwood treatment. In the unregulated harvesting treatment, the initial increases of these same species (original data not available) apparently peaked before regeneration counts were made. Therefore, a decline is noted between the 9th-year measurement and the 19th-year measurement. The selection treatments all show a slight decline in the numbers of intolerant species.



Mainly white pine, cedar and hardwoods.

Figure 2.--Changes in regeneration, by treatment.

Ratio of balsam fir seedlings to spruce seedlings.--The slow-growing shallow root systems of spruce seedlings often are not able to reach available moisture and compete with the faster-growing balsam fir unless: (1) the organic layers of the soil profile are reduced in thickness; (2) rainfall can better penetrate the overstory following an operation; or (3) rainfall during the crucial growing season is frequent and plentiful.

Disturbance in a spruce-fir stand caused by timber harvesting usually results in a reduction of the ratio of fir seedlings to spruce seedlings. The reduction in the depth of the organic layers by scarification and the greater penetration of rainfall because of tree removals trigger a relatively greater response in establishment of spruce than in establishment of balsam fir. In the absence of logging, natural mortality can also create conditions that improve the moisture regime in the forest floor.

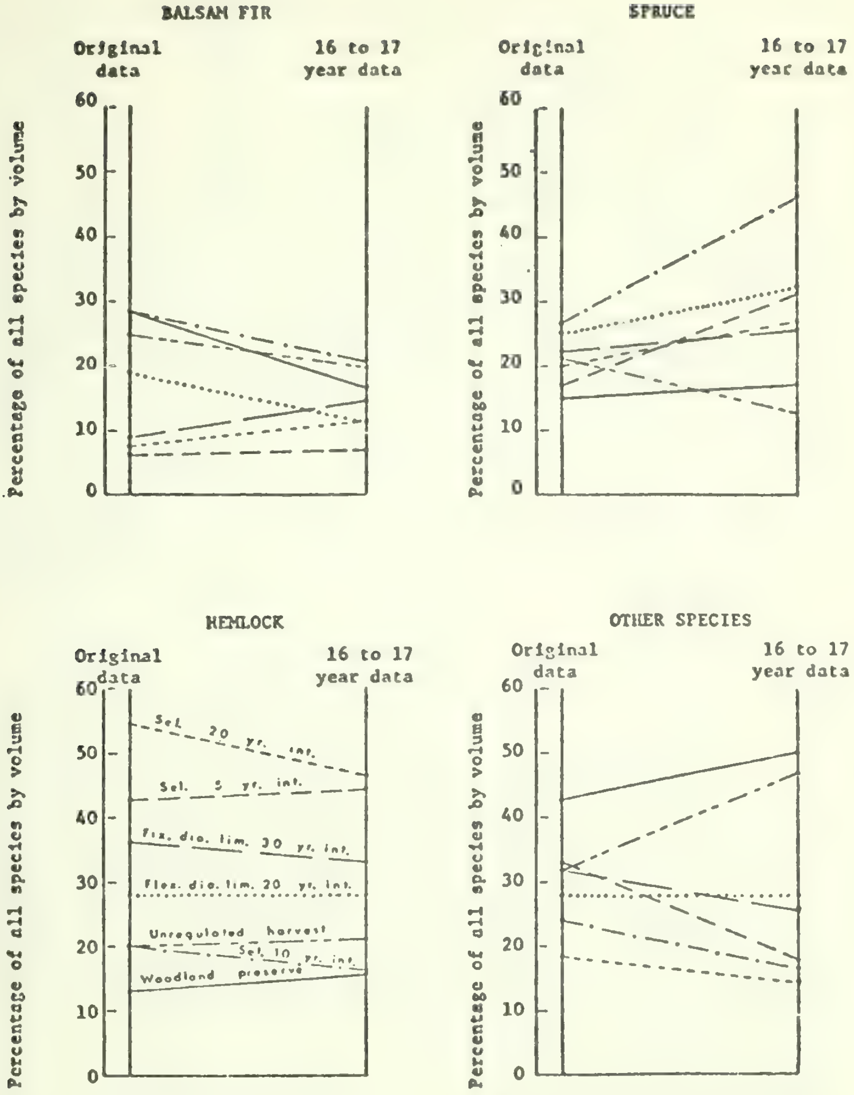
Immediately before the final removal of predominately spruce overstory trees in stands resulting from the shelterwood treatment, the fir-to-spruce ratio was 2:1. Eight years previously it had been 14:1. Unquestionably, this shelterwood operation was successful because a major goal was to increase spruce representation.

Since original data are not available we can only speculate about the ratio before treatment. The woodland preserve is perhaps indicative, however. The initial measurement resulted in the tabulation of a ratio of 28 fir to 1 spruce for this treatment. Currently it is 12 fir to 1 spruce. Originally, before excessive mortality, the ratio was perhaps significantly greater than 28:1.

All selection treatments display a reduction in the fir-to-spruce ratio--from about 5 to 7 fir for each spruce to a ratio of 4:1.

Composition changes in merchantable-size trees.--Changes in species representation after 16 to 17 years of observations is at best only trend-setting. And, variations based on volume in original compositional representations were pronounced (fig. 3).

The stands in the study area originally were about 85 percent softwood by volume:



Mainly red maple, paper birch, white pine, and cedar

Figure 3.--Changes in species composition, by treatment.

	Percent
Spruce	22
Balsam fir	18
Hemlock	30
Cedar and White pine	15
Hardwoods	15

In general, because of risk and poor quality, balsam fir is being reduced by silvicultural treatment. Conversely, spruce representation in stands under the most intensive treatments appears to be increasing. Hemlock, with widely varied original representations, shows little change. Other species, but primarily the poor quality red maple and other hardwoods, are changing in relation to the intensity of management. Hardwoods tend to increase with little or no management and decrease in relation to other more desirable species as cultural practices intensify.

The Selection System and Diameter Distribution

The normal or classic uneven-age forest is comprised of trees of several or all ages in which no age class can be recognized. Trees of all sizes are interspersed as individuals or in small groups. Regeneration may be found either in small openings or under dense overstory trees. But in order to be assured of sustained periodic yields from an uneven-age forest, it is essential that a balanced or near-balanced diameter structure be maintained. The characteristic of gradually decreasing number of trees in successively larger diameter classes is necessary.

Plotting number of trees by diameter classes on semilogarithmic paper is one way of determining whether or not an uneven-age forest has a balanced diameter distribution. The closer the plot resembles a straight line, the better balanced is the diameter distribution.

The original diameter distributions of the three selection treatments were not similar (fig. 4). The major difference was in the number of saplings in the 5-year-interval treatment. The stands receiving this treatment originally supported about one-half the number of saplings compared to the 10- and 20-year intervals. In fact, the original diameter distribution was considered balanced. However, the continual removal of poor-risk trees and other unwanted trees in the initial four harvest-TSI operations resulted in

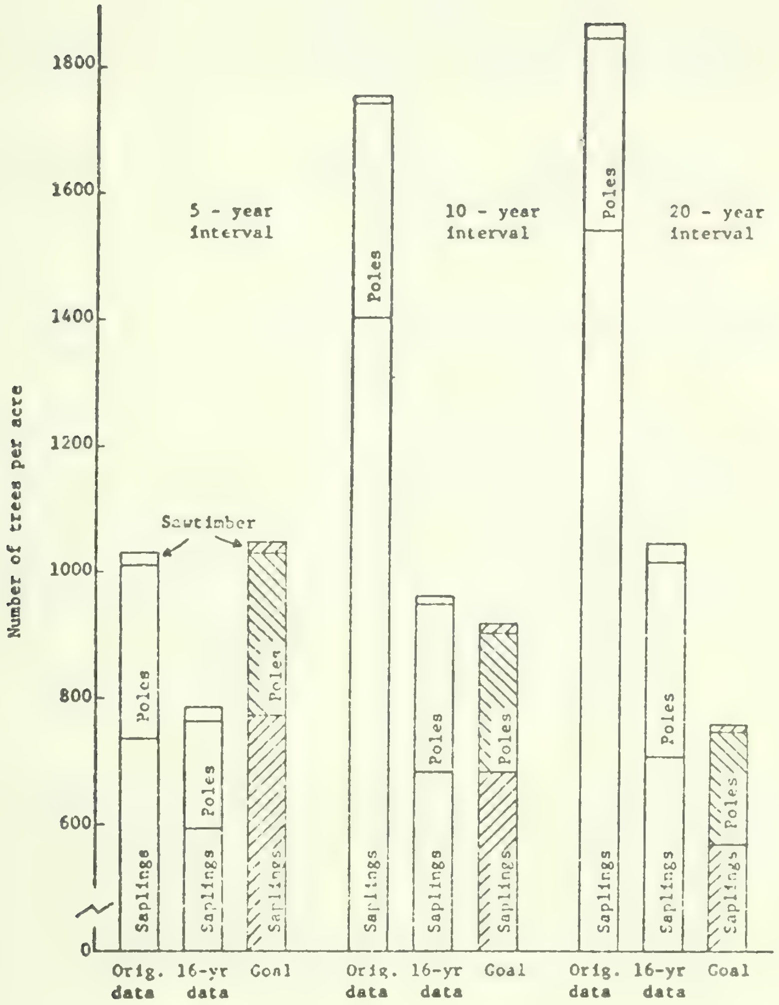


Figure 4.--Diameter-class distribution for selection-system treatments, by operating interval.

less-than-desirable stocking. Until stand density a again approaches the goal, only additional poor-risk trees will be removed in subsequent operations.

The 10-year-interval treatment area is balanced after two entries. The next combined harvest-TSI operation at 20 years will concentrate on the removal of poor-risk trees as well as excess trees in any diameter class. It is reasonable to assume that the current balanced state will be maintained.

The second stand entry for the 20-year-interval treatment at 20 years is expected to result in a reasonable state of balance.

All selection treatments displayed a reduction in the fir-to-spruce ratio between about the 10th year after treatment and the 20th year after treatment--from about 5 to 7 fir for each spruce to a ratio of 4:1.

During the same period, the ratio of fir to spruce changed slightly in the unregulated harvesting treatment--from 12 fir for each spruce to 11 fir for each spruce. In this treatment spruce is not favored; indeed, most spruce were removed during the commercial clearcutting. This reduction in spruce seed-source trees has perhaps negatively influenced the fir-to-spruce ratio.

IN CLOSING ....

Much can be done to improve the condition of spruce-fir stands. For long-term investment, the employment of commercial treatments utilizing silvicultural systems and skillful methods of harvesting are no more costly than no system at all and ill-timed harvests that fail to take into consideration the needs of the stand.

Indications of silvicultural potential from long-term experiments suggests that it is possible to increase growth, improve stand quality, change species composition, and control diameter distribution.

Immediate results from formerly mismanaged and undermanaged stands cannot be expected. But the continual application of approved commercial treatments designed to aid stands to produce near their capacity, will eventually mean larger profits to the landowner.

The measures suggested in this paper are considered sound and practical. I believe they can be undertaken at a profit.

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APPENDIX I

Cultural treatments and goals for various silvicultural systems and methods are as follows:

I. Species preference, where applicable, in order of desirability:

Red spruce/black spruce, white spruce, balsam fir, pine, paper birch, hemlock, cedar, other species.

II. Tentative optimum stand structures and goals for the selection system:

A. Species composition, in percent basal area--Spruce, 35-55 percent; balsam fir, 15-25 percent; white pine, 5-10 percent; paper birch, 5-10 percent; hemlock, 15-25 percent; cedar, 5-10 percent; other species, 5-10 percent.

B. Stand density, basal area per acre, at beginning of an operating interval for trees 0.5 inches (1.27 cm) dbh and larger:

1. 5-year operating interval--115 ft^2 (26.4 m^2/ha).

2. 10-year operating interval--100 ft^2 (23.0 m^2/ha).

3. 20-year operating interval--80 ft^2 (18.4 m^2/ha).

C. Diameter-class distribution:

1. Maximum size tree at end of an operating interval is 20 inches (50.8 cm) dbh.

2. Quotient ("q") between adjacent classes is 1.4.

D. Harvest limitations:

1. Initial harvest--up to 35 percent of gross volume for both the 5-year and 10-year operating intervals; up to 45 percent of gross volume for the 20-year interval.

2. Subsequent harvests--50 percent to 100 percent of net periodic growth for both the 5-year and 10-year operating intervals; 75 percent to 100 percent of net periodic growth for the 20-year operating interval.

E. Timber stand improvements:

1. Remove all cull, wolf, and other unwanted trees to 0.5 inches (1.27 cm) dbh and prune up to 75 spruce and pine per acre (185/ha) for both the 5-year and 10-year operating intervals; to 4.5 inches (11.4 cm) dbh and prune up to 50 spruce and pine per acre (124/ha) for the 20-year operating interval.

III. Objectives and constraints of the three-stage shelterwood system:

A. First harvest--remove overmature, defective, and slow-growing trees; remove less desirable species; create conditions favorable for the establishment of regeneration; increase growth rate of residuals. Limit removal to 50 percent of gross volume.

B. Second harvest--made about 10 years after first to further improve growing stock; increase growth of regeneration; and continue to establish new regeneration. Limit removal to two-thirds of gross volume.

C. Third and final harvest--made about 5-10 years after second harvest to remove all trees down to 2.5 inches (6.4 cm) dbh when stocking of regeneration is at least 85 percent and the area supports 1,000 or more trees per acre (2,500/ha) 2 feet (0.6 in) or over in height.

D. Stand improvement work--includes the deadening of culls and trees interfering with potential spruce seed trees.

IV. Diameter-limit management constraints and guides:

A. Flexible diameter basis:

1. Diameter limits, in inches (centimeters)

Species	First Harvest		Second Harvest	
	(in)	(cm)	(in)	(cm)
Balsam fir	6.5	(16.5)	6.5	(16.5)
Spruce	9.5	(24.1)	14.5	(36.8)
Hemlock	9.5	(24.1)	12.5	(31.8)

Pine	10.5	(26.7)	14.5	(36.8)
Larch	--	--	12.5	(31.8)
Cedar	--	--	7.5	(19.0)
Paper birch	7.5	(19.0)	9.5	(24.1)
Other hardwoods	6.5	(16.5)	5.5	(14.0)

2. Stand-improvement work limited to leaving some trees above limits for seed source and wind protection and removing some trees below limits to prevent their complete loss.

3. The operating interval is 20 years and the volume removed in subsequent harvests is limited to periodic net growth.

B. Fixed diameter basis:

1. Diameter limits, in inches (centimeters)

Species	All harvests (in)	All harvests (cm)
Balsam fir	All merchantable	
Spruce	9.5	(24.1)
Hemlock	9.5	(24.1)
Pine	10.5	(26.7)
Larch	All merchantable	
Cedar	7.5	(19.0)
Other hardwoods	7.5	(19.0)

2. Stand-improvement work is not scheduled.

3. Subsequent harvests are made when stand is operable for the same volume as originally removed.

V. Unregulated harvesting by the commercial clearcutting method--a brief description:

Most merchantable trees on operable areas are removed in a single harvest. No stand-improvement work is done. Small patches of merchantable trees considered inoperable are left to grow. The next harvest is made when it is operable for the same volume as originally removed.

APPENDIX II

Before treatment, parameter averages for the entire 400-acre study area were as follows:

Basal area--146 square feet per acre (34 m^2/ha).
Volume--2,075 cubic feet per acre (145 m^3/ha).
Number of trees less than 4.5 in. dbh--1,090 per acre (2,700/ha).
Number of trees 4.5 in. dbh and larger--360 per acre (890/ha).

Percentage species representation--

Species	Parameter		
	Volume[1]	Basal area[2]	No. trees[2]
Spruce	22	17	8
Balsam fir	18	24	56
Hemlock	30	28	11
Other	30	31	25

[1] Trees 4.5 inches dbh and larger.

[2] Trees 0.5 inches dbh and larger.

FIELD EXPERIENCES IN PRE-COMMERCIAL THINNING, PLANTING AND CONTAINER GROWING OF NORTHERN SOFTWOODS

by L. Oscar Selin, Chief Forester, Georgia-Pacific Corporation, Woodland Division, Woodland, Maine.

Abstract

In preparation for intensive logging mechanization and for the subsequent silvicultural treatments of clearcut areas the Woodland Division of Georgia-Pacific Corporation started a pre-commercial thinning trials in young softwood and mixed wood stands during the spring and early summer of 1970. Pre-commercial thinnings were intended to be a backbone of a large scale silvicultural system which relied upon natural regeneration of clearcut areas and early thinning of subsequent pre-merchantable stands. It was hoped that through this cycle of treatments the average diameter growth occurring on individual stems could be more than doubled in comparision to natural stands. It was also automatically assumed that the treatments would make considerable shorter rotations possible.

Only a few years later when the techniques of growing viable seedlings in containers had been fully tested and proven, it came obvious that even further reductions in length of rotations were possible for a private landowner who was willing to risk a modest investment on productive greenhouse facilities. As a result of these observations the Woodland Division of this corporation initiated in the spring of 1974 a comprehensive program on intensive silviclltural practices which consisted of raising container-type planting stock in large numbers and hand planting it on clearcut sites which in turn had been prepared for planting by heavy mechanized crushing and rolling equipment. It is expected that pulpwood rotations of twenty-five to thirty years and sawlog rotations of forty-five years are possible within the scope of this approach.

PRECOMMERCIAL THINNING OF SOFTWOODS

During the summer of 1970, a twenty year old burn which had naturally regenerated to a mixed stand of spruce, fir and low-grade hardwoods was released of hardwood overstory and the remaining softwoods were spaced out. The entire work was carried out by a six-man crew using lightweight power saws. The total acreage thinned amounted to seventy-one acres and a total of one hundred twenty nine mandays were required to complete the project. A rate of productivity of 2,500 trees or 0.55 acres per manday was achieved. The original stand density was six thousand stems per acre and it was reduced to one thousand four hundred stems per acre when the hardwood overstory was removed and the softwoods spaced out. This was somewhat higher than desired but a fear of wind and snow damage prevented from removing any greater number of stems. The basal area of the stands prior to thinning was sixty-four square feet per acre and fifty-one square feet were removed leaving only a basal area of thirteen square feet per acre for residual stand. The average DBH after the thinning had taken place was 1.35 inches.

The major problem in this type of silvicultural work is the great number of stems to be handled. While the work is in progress, the stems which have been cut occasionally pile up to the waist height and thereby limit the movement and efficiency of workers. Some idea of the size of this problem is given by making reference to the total number of stems involved in this particular operation. We estimated that a total number of 322,500 stems in sizes of 0.5 inches DBH and larger were removed in the course of this seventy one acre operation. Another fifty thousand could have been easily removed if we did not have to worry about snow and wind damage. In order to minimize this problem with numbers we have opened corridors with mechanized crushers in all of our later precommercial thinning projects and thereby reduced the stems to be manually handled by half. So far approximately one thousand acres have been handled in this fashion.

The responses to thinning have been measured only on comparative terms to the average annual diameter growth of our natural spruce-fir stands. Observations extending over several decades have confirmed an average annual growth rate of 0.10 inches per year on medium sites. Against this level of growth our permanently established plots in the thinned area indicate, at the end of the first five years, an average growth rate of 0.25 inches per year. If this rate of growth can be maintained over the next fifteen years, a harvestable crop of pulpwood with an average DBH of 6.25 inches had been raised in forty years. This in comparison to sixty to seventy years required to raise a crop of trees of a similar size in natural stands.

GROWING SEEDLINGS IN STYROBLOCK CONTAINERS

This system of handling and growing seedlings was introduced to Georgia-Pacific Corporation's operations by its Forestry Research Manager, Philip F. Hahn in Eugene, Oregon. He has further refined it to such a degree that it is presently known under his name as a Quarterblock System. The core of this system is a polystyrene moldable quarterblock container. It has proven to be the most superior among the several types of containers. It supports an outstanding seedling development at the nursery and also lends itself well for a high degree of mechanization at the nursery and in the field.

This container is produced in a quarterblock form in two different sizes. The smaller one, #2, is five inches wide, fourteen inches long and 4.5 inches high. It has forty eight cavities, each cavity being one inch in diameter and slightly tapered towards the bottom. The large type, #8, quarterblock container is five inches wide, fourteen inches long and six inches high. It has twenty cavities, each 1.5 inches in diameter and also tapered towards the bottom. One cavity in #2 container holds 2.5 cubic inches of soil and produces a smaller tree than is possible in #8 which contains eight cubic inches of soil. Each container has its place. The smaller container is used in routine operations and the larger one in special areas where higher costs for larger seedlings can be justified. Cleaned and disinfected blocks are reusable several times which saves material and cost. Since the cost of the containers is largest single expense item in container operation, considerable savings can be effected by recycling the blocks.

In the filling of containers a light weight mixture of peat and vermiculite is used. The soil loading and seeding operation is mechanized and the last step in loading is the covering of seed with layer of grit. When the whole operation is fully automated over three hundred thousand container cavities can be loaded and seeded in eight hours.

Since the container cavities hold only small amounts of soil, frequent irrigation and fertilization are needed. This is done normally two or three times a week during the active growing season. In all cases before the seedlings are ready to go to the field they must be hardened. This is generally done with a combination of measures which include the exposing of the seedlings to systematic moisture stresses, the shortening of the photo period and the manipulation of the nutrient diet.

The type of houses used to shelter the growing seedlings by Georgis-Pacific Corporation in the Northeast are of a double layer polyethylene and steel frame construction. They are equipped with a heating and ventilation system which is controlled by thermostats. Two crops per year are raised and artificial lighting is used to accelerate growth. These types of houses give excellent shelter against the extremes of the weather in the Northeast and they also support an excellent seedling growth for a relatively low cost while staying close to natural growing conditions.

PLANTING

The fully grown and hardened seedlings are shipped to the planting site in their original quarterblock containers. They can be boxed for longer trips but they can be also conveniently transported as they are in slightly modified pick-up trucks. At the planting site the quarterblocks are placed in the backpack carriers which handle up to nine quarterblocks or approximately 430 seedlings and have a total loaded weight of twenty seven pounds. Each tree planter carries his own supply of seedlings while he plants the trees.

The carrier is so designed that a double lock system operated by the tree planter moves one quarterblock into the bottom compartment. This quarterblock could be then removed and placed in a belt holder where the seedlings are in easy reach to the planter. After punching a hole of the same shape as a rootplug into the ground, he can extract the seedling from the belt holder and place it into the hole. As soon as the supply of seedlings is depleted from the quarterblock in the belt holder, the empty quarterblock is placed into the carrier through the top to return it for another use while it is replaced with a fully stocked quarterblock.

The planting rate with quarterblock containers is very good. It is generally twice as high as the bareroot planting rate under similar conditions. Planting rates of 1,500 seedlings per manday have been easily reached in the Northeast operations of this corporation and it is expected that a rate of 2,000 seedlings per manday will be reached in the near future.

PLANTING SITE PREPARATION

All the sites to be planted are prepared prior to planting, and two types of equipment are presently used. In New Brunswick operations of this corporation the so-called shark finned barrels with anchor chains are pulled by Caterpillar D-8 Tractor and in Maine a single drum-type Marden B10 brush cutter is being drawn by model 668 Clark rubber-tired skidder.

This work needs to be done in order to make the sites accessible to tree planters and to break up the heavier layers of humus. It also leads to elimination of great numbers of competive shrubs, seedlings and trees. No scalping and only very light scarification effect is being sought. No sedimentation of adjoining waters as a result of this work has been observed nor expected in the future.

HOW DO STYROBLOCK SEEDLINGS PERFORM

The West Coast Divisions of Georgia-Pacific Corporation have been engaged in large scale containerized seedling production since 1971. The annual growing capacity of the present facilities is about fifteen million seedlings, and all these nurseries use the quarterblocksystem developed by Philip Hahn. We are also raising 1.5 million seedlings annually by this same method in the nurseries located in Maine and New Brunswick, Canada.

Comparison tests to bare-root seedlings in all of West Coast locations have shown that the containerized seedlings nearly always out-produce bare-root stock in survival and growth rate. The survival difference is often substantial. A ten to twenty per cent higher survival rate is quite common. On harsh dry sites as high as forty per cent survival differences have been observed.

In the Northeast operations the experience with the styroblock container stock is limited more or less to one growing season but it shows that the styroblock seedlings can be planted throught the summer with excellent results and they do survive well even under the harshest conditions.

STATUS OF FERTILIZATION AND NUTRITION RESEARCH IN NORTHERN FOREST TYPES

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Orono, Maine

Abstract

Forest fertilization is a useful tool that, when combined with other silvicultural practices, results in increased forest growth. Many experiments have demonstrated that both hardwoods and conifers of the northern forest respond to the addition of one or more nutrients. Examples of pitfalls and successes are given. Present status of research and future research needs are discussed.

GREATER DRAIN on the northern forest is expected in the not-distant future. Obviously more raw material will have to be grown and harvested at shorter rotations and on less land.

Liming and fertilization are useful tools which, when combined with other ameliorative site treatments and silvicultural practices, result in increased forest growth.

In this paper I present a digest of available information and summarize the status of research in progress on forest fertilization in northern forest types, with emphasis on the work being done in New England and the Maritime Provinces of Canada.

This paper does not contain all details and does not pretend to be complete. The area is large, the forest conditions are diverse, and the research activities are complex. Attempt is made to point out the examples of pitfalls as well as successes in forest-fertilization efforts in northern forests.

AVAILABLE GUIDELINES

At the outset, something has to be said about the knowledge available worldwide. During the last quarter century, intensive research activities in forestry and forestry-related disciplines such as soil science, tree physiology, and biochemistry have formed a basis for forest tree nutrition as an area of study in many schools and experiment stations in Europe, Canada, and the United States. Thus there is a considerable body of literature on both basic and applied aspects of forest fertilization, published worldwide.

Knowledge accumulated in recent years made possible four symposia, three international and one regional in scope, plus a workshop held recently in Canada. Two international symposia were held in 1967, one at the University of Florida; the second, organized by the International Potash Institute, was held in Finland. The third symposium, sponsored by FAO/IUFRO, was held in Paris, France, in 1973.

In recent years forest fertilization received considerable attention in northern forest types. The current knowledge on activities taking place in the northeastern United States and Eastern Canada were discussed at the symposium held in Warrensburg, N. Y. (Northeastern Forest Experiment Station 1973); at the Fourth North American Forest Soil Conference held in Quebec, Canada (Armson et al. 1975); and at the recently held workshop in Ontario (Environment Canada 1974).

In addition to the most recent research findings, the participants presented a digest of existing literature. If it were not for these proceedings, the researcher would be forever looking to article sources or collecting scattered papers of diverse research published in many journals and languages.

EFFECTS OF WHOLE-TREE HARVESTING

The changes in the management practices from uneven-age to even-age silviculture is a common occurrence. In certain instances this involves complete stand removal. Previously unusable species, sizes, and qualities are now marketable. Significant acreage of spruce-fir forest is being salvaged to minimize the losses caused by spruce budworm.

Changes of this kind, which result in more biomass removed from the forest, are causing concern about depletion of soil nutrients and possible site degradation. We are very short of detailed information on this subject for New England conditions, but some valuable data are available from other regions, and an attempt to obtain additional information is in progress.

The effects of wood harvesting on the nutrient status of spruce-pulpwood stands in Quebec were discussed by Weetman and Webber (1972). They concluded that "it is unlikely that the full tree logging will result in any reduction in growth, due to nutrients removed, during the second rotation of trees. However, there is a possibility full-tree harvesting on sites of marginal fertility and low in organic matter may eventually require an addition of Ca, K, and N."

Recently, changes in nutrient status were assessed on spruce-fir sites harvested by strip-clearcutting in which slash was left in place, removed, or burned. Eight years after harvest, the clearcut areas showed an increase in both pH and percent base saturation, but concentrations of N and P were comparable to those found in the residual forest. There was no evidence of site degradation from strip-clearcutting (Czapowskyj et al. 1976).

Young and Guinn (1966), and Young and Carpenter (1967), in the context of complete-tree utilization concept, provided data on chemical elements in the wood, bark, and leaves of the major species of different ages. The data provide a basis for calculating nutrient budget and estimating nutrient losses due to timber harvesting in Maine.

NUTRIENT AVAILABILITY AND DEFICIENCY

Forest fertilization is a supplement of essential nutrient elements that are lacking in a soil or are not available in adequate quantities for optimum tree growth. Thus a knowledge of soil fertility, the establishing of tree needs, and the identification of deficient elements are essential to a meaningful fertlization program.

Nutrient deficiencies have been observed in coniferous plantations established nearly 50 years ago on abandoned agricultural land in the State of New York (Heiberg and Leaf 1960). Diagnostic techniques of determining soil-nutrient deficiences--mainly K--were studied; and the responses to fertilization were documented (Heiberg and White 1949 and 1951). The pioneer work by Mitchell and Chandler (1939) clearly identified lack of available N as a critical factor in the growth of many hardwood species on many sites in the United States Northeast.

Foliar analysis seems to provide a valuable tool for diagnosing nutrient deficiencies and relationships in tree-growth parameters. However, it does not tell enough about the soil fertility.

Valuable information on foliar nutrient contents for major species growing in Maine was provided by Young and Guinn (1966). Swan (1966 and 1971) provided basic information for evaulating the results of foliar analysis and suggested critical levels of deficiency, sufficiency, and luxury consumption for major Canadian species.

Schomaker (1973a) studied foliar nutrient concentrations of fertilized mature red spruce (_Picea_ _rubens_ Sarg.) in Maine and compared his data with those reported by Young and Guinn, and with the critical levels suggested by Swan. From these comparisons, Schomaker concluded that the foliar N levels of red spruce stands growing in Maine were within the deficiency range, whereas P, K, Ca, and Mg were sufficient for good growth; and some of them were even approaching the luxury-consumption levels.

Assuming that Swan's critical values could be extrapolated to New England conditions and to all age classes, one might expect a marked response by red spruce to N applications. However in assigning the critical values based on foliar analysis alone for any element and for any of the species, extreme care must be taken. Time and method of sampling are of great importance. Nutrient levels in the foliage vary with the season. In red spruce, for example, nutrient levels vary among different soils and locations within the same soil series (Safford and Young 1968), as well as with the location of the foliage in the crown (Young _et_ _al_. 1967), and with the foliage age (Safford 1970).

Hoyle and Mader (1964) reported that different growth parameters related differently to tree nutrition. Height growth correlated better with Ca levels, and basal-area growth with K; and the volume growth was related to available soil moisture.

RESPONSE TO FERTILIZATION

Northern Hardwoods

In their summary paper on fertilizing eastern hardwood species, Auchmoody and Filip (1973) emphasized the following points:

1. Some hardwood species have potential for greater response to improved fertility.

2. N is the primary growth-limiting element on many sites, but response to P and other elements can be expected on some sites when used with N.

3. Response to N is rapid and easily observed in sums of tree growth and foliage color and size, but duration of response is not yet known.

Since the Auchmoody-Filip paper, some additional studies have been reported.

Bjorkbom (1973) tested the effects of N, P, and K on the growth of paper birch (Betula papyrifera Marsh.) in sand culture and found that seedling growth improved with increasing supply of N. Three to 4 percent N in the foliage seems to be adequate for seedling growth. There was no response to P and K applications. But response by yellow birch (Betula alleghaniensis Britton) to P had been demonstrated in a pot-culture experiment with a Vermont soil (Hannah 1973). This confirms earlier work by Hoyle (1965, 1969, 1970, 1971) in New Hampshire.

Field trials of lime plus N-P-K to a 90-year-old stand resulted in increased biomass of fine absorbing roots throughout a podzol soil profile (Safford 1974). Nutrient content of these roots was elevated above those of the control, providing a source of enrichment to the deeper soil horizons as a result of surface application of fertilizers. Diameter growth of these mature trees was also substantially increased: sugar maple (Acer saccharum Marsh.) 158 percent greater than control, paper birch 69 percent, yellow birch 51 percent and beech (Fagus grandifolia Ehrh.) 20 percent (Safford 1973b).

An application of N-P-K fertilizer plus lime to the soil after clearcutting and site scarification increased biomass after 4 years by 300 percent over the control. Unfortunately pin cherry (Prunus pensylvanica) responded so strongly that the growth of birch and other desired species was hindered (Safford and Filip 1974). On another site that was heavily scarified and deep-limed, planted yellow and paper birch responded dramatically to control of competition and N-P-K fertilizer. Fertilized and released yellow birch were 20 percent taller and 120 percent greater in basal area; paper birch were 50 percent taller and over 400 percent greater in basal area than the control or trees released only (Hoyle 1975).

Not all hardwood plantations have shown positive response to fertilizers. In southern Ontario, von Althen (1973) reported little or no response to added nutrients by hardwood seedlings. This lack of response is probably due to having fertile planting sites and good site preparation. Von Althen (1973) concluded that "if hardwood planting is restricted to good planting sites with deep, moist, but well-drained soils, there is little need for fertilization... However...hardwoods are often planted on sites that do not meet the foregoing criteria. Fertilization may be necessary on these marginal sites."

Stone and Christenson (1974) reported no diameter-growth response to N, P, or K treatments in factorial combinations in a pole stand of sugar maple in Michigan. Release increased growth over controls by about 80 percent. Foliar N of controls was close to satisfactory levels (2 percent) given by Mitchell and Chandler (1939) and Mader et al. (1969). Concentration of nutrients in foliage of released trees decreased despite the growth response. Stone and Christenson attributed this decrease to a dilution effect and suggest that some site factor other than nutrition might be limiting growth in this Michigan stand (Stone and Christenson 1975).

A combination thinning-and-fertilizer study with 25-year-old paper birch in Maine also showed greatest growth response to thinning, 100 percent over controls; but fertilizer treatments stimulated growth by an additional 30 percent. Foliage nutrient levels in released-only trees increased over controls; and each element--N, P, K, and Ca·Mg (in lime)--whenever added, increased nutrient levels above that of released-only trees (Safford, L.O.: unpublished data on file at U.S. Forest Service Forestry Sciences Laboratory, Durham, N.H.).

These conflicting results point to a need for caution when extrapolating data from one location or species to another. They also suggest that standardized research methods and analysis would benefit evaluation of results of fertilizer studies.

Conifers

Forest fertilization activities in coniferous forests of the eastern United States have been summarized by Safford (1973a), and in eastern Canada by Krause (1973). However, the most relevant facts will also be repeated briefly in this section.

Long- and short-term studies have been conducted in the Adirondack mountains in New York State. The summary of results have been given by Heiberg *et al*. (1959 and 1964) and Leaf *et al*. (1970 and 1975). Information has been used to improve productivity of soil deficient in K through application of potash to red pine (*Pinus resinosa* Ait.) plantations.

I do full justice to the researchers of SUNY for their manifold contributions to red pine and potash fertilization relationships in this brief review. Those interested in specifics are referred to the more detailed accounts: (Fornes *et al*. 1970; Kawana *et al*. 1969; Madgwick *et al*. 1970; White 1954 and 1956; Wittwer *et al*. 1975).

Information on white pine (*Pinus strobus* L.) is limited. Studies conducted in Pack Forest, New York, showed a response of a young plantation on a coarse sandy glacial outwash soil to the addition of logging slash, K, and complete fertilizer. The responses were immediate and lasting. No response to N was observed (Heiberg and Leaf 1960). The growth response of white pine plantations on coarse-textured droughty soil in Maine to N (urea), K, and N-P-K, were studied by Stratton and others (1968). The response in terms of basal-area growth were similar to those obtained on the Pack Forest. The stand responded to K and N-P-K application, but not to N alone. On the other hand, Schomaker (1973a) reported that the 10-year radial growth of a medium-aged white pine stand in southern Maine correlated positively to foliar N and negatively to P. Correlations between foliar K and diameter growth were weak.

Spruce-Fir

An extensive research program is under way in the northeastern United States and eastern Canada. Forest industries in Maine in cooperation with the School of Forest Resources, University of Maine, are currently conducting a series of field studies.

Experimental plots in nearly-mature spruce-fir stands were fertilized with 10-10-10, equivalent to 150 pounds per acre (168 kg/ha), each of N, K_2O, and P_2O_5 singly and in combination, and urea equivalent to 150 pounds per acre of elemental N. The preliminary results indicated that, after three growing seasons, only one stand responded significantly in basal-area growth. Increased growth was due to N-P-K treatments and due to N alone in urea form (Schomaker et al. 1973). The follow-up remeasurements will yield additional information in respect to response duration and the explanation as to why two other stands did not respond.

Our Northeastern Forest Experiment Station Unit in Orono, in cooperation with Georgia-Pacific, has recently established a study to determine how a young stand with pioneer northern hardwoods in the overstory, and a spruce-fir understory, will respond to thinning plus lime and fertilizer treatments. The question asked is if the hardwoods will respond so that a merchantable product can be harvested at a shortened rotation and if the spruce-fir in the understory will benefit from lime, N, and P fertilization.

In another study, the effects of site preparation, lime, and N-P-K, fertilizer treatments and control of competition on growth of black and white spruce (Picea mariana [Mill.] B.S.P. and Picea glauca [Moench] Voss) planted on a chip-harvester clearcut are presently being tested.

In the early 1960s an extensive research program had been initiated in the Maritime Provinces and in Quebec. Numerous tests and long-term studies had been established by the Pulp and Paper Institute of Canada, Canadian Forestry Service, provincial governments, and universities. It was soon recognized that N was deficient in the vast areas of northern coniferous boreal forests (Weetman 1962) and that northern coniferous forests will respond to N applications.

Available reports (Weetman 1968, 1971, 1975; Weetman et al. 1974) revealed strong responses of black spruce to N fertilization. The responses were manifested in height, diameter, and volume growth.

Stand thinning and fertilization relationships were demonstrated. a 65-year-old stand was thinned by 25 and 50 percent and fertilized with urea at the rates of 100 and 400 pounds per acre (112 and 448 kg/ha).

The stand responded to the N treatment after 1 year and to thinning only after 7 years. The basal-area growth was not increased by 25-percent thinning, but was increased by 50-percent thinning; however, it always was increased by the addition of N. The 10-year growth increases over control were: 130 to 290 ft^3 (9.1 to 20.3 m^3) for 100 pounds (112 kg) N and 238 to 297 ft^3 (16.6 to 20.8 m^3) for 400 pounds (448 kg) of N per acre (hectare).

Preliminary results from fertilization data obtained in New Brunswick (Krause 1973) are encouraging. Krause stated "that N shortage is commonly limiting growth in pole-size and maturing conifer stands and that substantial growth increases can be obtained with addition of fertilizer N. Under certain site conditions, tree growth may also be improved by the addition of K and P".

The growth response of a 35-year-old white spruce plantation due to K treatments was reported from Quebec. Applications of 84 lbs/acre (94 kg/ha) K alone or in combination with 102 lbs/acre (114 kg/ha) N produced during a period of 10 years 4.0 and 3.8 cunits (11.3 and 10.8 m^3) respectively of extra wood (Gagnon *et al*. 1976). Response was due to K only. On the *other* hand, Timmer (1976) reports that in Nova Scotia neither young balsam fir (*Abies balsamea* (L.) Mill.) fertilized with 400 lbs/acre (448 kg/ha) of urea N, or semimature white spruce stands fertilized with 100 and 200 pounds of urea N per acre (112 and 224 kg/ha), resulted in increased basal-area increment 5 years after fertilization.

A recent unpublished report on a Canadian Interprovincial Forest Fertilization Program (Weetman *et al*. 1976) provides an analysis of 5-year growth responses of major coniferous species in eastern Canada. It was evident that the responses of the spruce-fir stands to N fertilization were significant, but maximum gains were obtained from combined high N and P or high N and K, or high N and PK treatments. The effects of P and K were less important. White spruce stands in New Brunswick that were also affected by spruce budworm either did not respond to fertilizer treatments, or the results were inconclusive.

The growth responses of jack pine (*Pinus banksiana* Lamb.) to fertilization were observed in a few instances in Canada. The young stands growing in well-drained soils were fertilized with N (urea) and superphosphate. The treatments increased the needle weight of the foliage, but not height growth (Calvert and Armson 1975). The authors concluded that fertilization of young jack pine growing under conditions as in the study is not necessary.

In another study a 40-year-old stand responded to N fertilization, and the ammonium nitrate was found to be superior to the urea form of N. The growth responses were associated with increased needle weights and increased foliar N concentration (Weetman and Algar 1974).

FOREST FERTILIZATION IN PRACTICE

In Maine, a spruce-fir forest was limed and fertilized at several locations with the objective of demonstrating increased growth due to fertilization. One such demonstration area was established at the Penobscot Experiment Station in 1970. Lime was applied at the rate of 2 tons per acre (4.5 metric tons/ha), and fertilizer, N-P-K 15-15-15, at the rate of 120 pounds per acre (134 kg/ha). Fertilizer was applied on both limed and unlimed plots. Band dendrometers were installed and periodic observations have been made. At the present time the data are being analyzed.

Maine forest industries are conducting some fertilization experiments on their own.

Scott Paper Company has fertilized in 1967 about 300 acres (121 hectares) of mature and regenerated spruce-fir stands. Ammonium nitrate at rates of 100, 150, and 200 pounds of N per acre (112, 168, and 224 kg/ha) was applied. Preliminary data showed that overall the stands responded positively to fertilization. Balsam fir responded better than spruce. However there was no consistency as to the rates of fertilizer applied. In certain instances the volume growth of spruce actually decreased.

Great Northern Paper Company fertilized experimentally clearcut areas and second growth spruce-fir stands in 1968. On the clearcut areas 0.75 tons/acre (1.68 metric tons/ha) of lime and 600 pounds per acre (673 kg/ha) of 10-10-10 N-P-K was applied. Seven years later the area was heavily overgrown with raspberries with a few stems of softwood or hardwoods remaining. In mature spruce-fir stands urea or N-P-K (10-10-10) was applied at the rates 100, 150, and 200 pounds per acre (112, 168, 224 kg/ha) of each element. Seven years later responses were observed as increased height growth and dbh, but there was no certainty that the fertilized plots showed superior growth or that the control plots exhibited marginal growth.

The Dead River Company has fertilized over 300 acres (121 hectares) of mature and second growth stands of spruce-fir, hemlock (*Tsuga canadensis* (L.) Carr.), mixed softwood and hardwood stands. The rates varied from 50 to 150 pounds of N urea per acre (56 to 168 kg/ha). Preliminary measurements indicate trends of increased growth. Another study involves ground application of NP and some minor elements in various combinations.

The Oxford Paper Company is also experimenting with lime and N-P-K fertilization. Data are being collected and evaluation will be made.

Georgia-Pacific has fertilized small plots of Norway spruce (*Picea abies* (L.) Karst.) and Japanese larch (*Larix leptolepis*) plantations. Ammonium nitrate at the rate of 400 pounds per acre (448 kg/ha) was applied in 1971. Preliminary observations indicate an increase in height growth. The company is also experimenting with applications of lime. In 1975 lime at a rate of 2 tons per acre (4.5 metric tons/ha), was experimentally applied to about 60 acres (24 hectares) of pioneer northern hardwoods and softwood stands.

ONGOING RESEARCH

To assess the course of ongoing forest-fertilization research in northern forests, a questionnaire was mailed to the researchers engaged in this in the New England States and the Maritime Provinces. From the response to the questionnaire, it is estimated that at present there are approximately 70 studies about equally divided between the northeastern United States and eastern Canada. The species studied and their frequencies are given in table 1.

Conifers are the prime subject of investigation in Canada, whereas the hardwoods get most attention in New England. The objectives of the studies in descending order are: tree growth increase, stand establishment, and seed and sap production.

Table 1.--Frequency of ongoing fertilization research in northern forest

Species	Northeastern U.S.	Eastern Canada	Total
CONIFERS			
1. Red spruce	4	8	12
2. Black spruce	1	9	10
3. White spruce	3	7	10
4. Balsam fir	3	7	10
5. Jack pine	-	5	5
6. Red pine	2	-	2
7. Eastern hemlock	1	-	1
Total	12	36	48
HARDWOODS			
1. Sugar maple	9	3	12
2. Yellow birch	4	-	4
3. Paper birch	3	-	3
4. Red maple	3	-	3
5. White ash	3	-	3
6. Black cherry	3	-	3
7. American beech	2	-	2
8. Pin cherry	1	-	1
9. Hybrid poplar	1	-	1
Total	29	3	32

The application of N in the form of urea and ammonium nitrate at rates from 50 to 400 pounds per acre (56 to 448 kg/ha) of elemental N are used. The application of P in the form of superphosphates range from 25 to 200 pounds per acre (28 to 224 kg/ha) of elemental P. K is used less frequently, and lime the least.

A few studies included micronutrients. In one instance the effects of the municipal sewage sludge are being investigated. There are no indications of use of legumes.

COMMENTS

After discussing the established facts of soil nutrient deficiencies, citing examples of responses obtained from fertilization, and summarizing the research in progress, I have to say something about future research needs.

- The importance of forest health cannot be overrated. Thus research is needed on the health of fertilized forests, including population dynamics of insects and the changes occurring in pathogenic organisms.
- There is an increased awareness of disposal of municipal sewage sludge and farm manure. The possibilities of disposing of it on the forest warrants consideration.
- Site preparation and fertilization of extremely marginal forest areas, including the mechanical drainage of swamps and bogs, should be studied and evaluated.
- Introduction of nitrogen-fixing legumes and microorganisms, as an alternative for mineral fertilizer applications, would reduce the cost and energy needed in processing and applying fertilizers. This subject deserves adequate attention.
- Possibilities of using the coated slow-releasing fertilizers should be explored.
- Improved techniques of soil and foliar analyses and the calibration of results for estimating site productivity and fertilizer needs are desired.
- Future research on soil productivity, natural fertility, or stand responses to ameliorants and fertilizers should be correlated with a kind of soil series or soil association.

If the physiologically healthy forest is to be grown, cultured, protected, and harvested, the land manager has to be aware of the potentials offered by intensive silviculture, including fertilization for a given site and conditions. At present information is still inadequate. Research is needed to produce answers.

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SITE CLASSIFICATION FOR NORTHERN FOREST SPECIES

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Abstract

Summarizes the extensive literature for northern forest species covering site index curves, site index species comparisons, growth intercepts, soil-site studies, plant indicators, physiographic site classifications, and soil survey studies. The advantages and disadvantages of each are discussed, and suggestions are made for future research using each of these methods. Suggests a complementary framework that coordinates site quality, yield, and forest land classification. Discusses how this complementary framework can help in practicing more intensive timber management.

THE QUANTITY AND QUALITY of timber yield closely depends upon forest site quality. Accordingly, one of the first steps for intensively managing forest land is to determine the site quality of land for various trees so that the most productive and valuable tree can be selected for each parcel of land. Armed with site and yield information, a forest manager can estimate future wood supplies, and thus can make realistic decisions about future costs and benefits of intensive forest management, land acquisition, and industrial investments.

Estimating site quality for forest land has been a primary concern of American foresters since the early days of our profession. An extensive volume of literature has accumulated regarding methods for estimating site quality in the United States (Carmean 1975). Likewise Canadian foresters have long been concerned with site quality estimation and with methods of forest land classification and mapping (Rennie 1962, Rowe 1962, 1971, Burger 1972).

I have three goals for this paper. First, I will give an inventory of the American and Canadian site quality research already accomplished for northern forest species. Second, I will try to show how these accomplishments can be joined into a complementary framework for site quality estimation, yield prediction, and forest land classification. And third, I hope to show how this complimentary framework can guide us in making decisions about where, what, and how intensively we should manage timberlands in the future.

INVENTORY OF SITE QUALITY RESEARCH

Site Index Curves

Site index based on height growth is the most widely accepted method for estimating site quality in the United States (Carmean 1975). Height and age measurements from free-growing, uninjured, dominant, or dominant and codominant trees are used with a family of height-age (site index) curves to estimate total tree height at a specified index age. For most northern species 50 years is the index age. The site index method is accurate and simple to use when (1) suitable trees are available for measuring site index, and (2) when accurate site index curves are available.

Many site index curves have been constructed for northern forest species, but most of these curves are for conifers (table 1) and relatively few are for valued hardwood species (table 2) such as yellow-birch, black cherry, and white ash. Most of the site index curves now in use are older, "harmonized" curves that accompanied regionwide normal yield tables. These harmonized curves are not based on actual tree height growth studies, but on dominant and codominant tree height and age measured from growth and yield plots scattered throughout a particular forest region. An average height-age curve is calculated and this curve is used to construct a family of proportional site index curves all having the same shape or pattern of height growth. Thus harmonized curves are based on the assumption that the pattern of tree height growth is the same for all site classes, localities, and soil conditions included in a regional yield study. We now know that this assumption is not valid and that height growth patterns may vary greatly (are polymorphic) for many species that grow on contrasting sites, or that have a wide geographic distribution (Carmean 1970, 1975).

For intensive timber management we need site index curves that are more accurate than harmonized curves. Stem analysis is the method most favored for developing more accurate site curves, and we need such curves for all important northern forest species. Because height growth patterns may vary from area to area we may have to construct separate site curves to fit certain localities, or certain soils and climates. For example, stem analysis data (Hegar and Lowry 1971) indicate that Plonski's (1960) harmonized curves are applicable to black spruce (see Appendix list of common and scientific names) in Ontario and Quebec. However, black spruce in the maritime climate of eastern Canada has much different height growth patterns than in continental areas (Page and van Nostrand 1971), thus separate curves may be needed for the maritime areas. In contrast, northern hardwoods in the White Mountains of New Hampshire (Solomon 1968) have height-growth patterns similar to hardwoods in Vermont's Green Mountains (Curtis and Post 1962a), thus the site curves prepared for Vermont northern hardwoods should be usable in New Hampshire.

Table 1.--SITE INDEX CURVES FOR NORTHERN CONIFER FOREST SPECIES

Species	Area	Reference
Jack, red, and white pines	Lake States	Brown and Gevorkiantz (1934)
Jack pine	Lake States	Sterrett (1920), Wackerman *et al.* (1929), Eyre and LeBarron (1944), Gevorkiantz (1956a)
Jack pine	Saskatchewan	Kabzems and Kirby (1956), Jameson (1963)
Jack, red, white pines; black spruce	N. Ontario	Plonski (1960), Payandeh (1974a)
Red pine	N. Minnesota	Eyre and Zehngraff (1948)
Red pine	Lake States	Gevorkiantz (1957e)
Red pine	Central New England	Reed (1926)
Red pine	Connecticut	Bull (1931)
Red pine	Northeast and Lake States	Spurr (1956)
Red pine	Quebec	Phu (1974)
Red pine	Ontario	Stiell and Berry (1973b)
Red pine	Pennsylvania	Kinsley and Bartoo (1967)
Red pine	Illinois	Gilmore (1967)
Red and white pines	S.E. Ohio and S. Indiana	Gaiser and Merz (1953)
Red and white pines	S.E. Ontario	Ardenne (1950)
Red and white pines	Quebec and Ontario	McCormack (1956), Horton and Bedell (1960)
Red, white, and Scotch pines	Vermont	Hannah (1971)
White pine	N. England and Mid-Atlantic States	Frothingham (1914)
White pine	New England	Leak *et al.* (1970)
White pine	New Hampshire	Husch (1954)
White pine	New Hampshire	Barrett and Goldsmith (1973)
White pine	Wisconsin	Gevorkiantz and Zon (1930)
White pine	Lake States	Gevorkiantz (1957d)
White pine	S. Appalachians	Barrett (1934), Vimmerstedt (1959, 1962), Doolittle and Vimmerstedt (1960), Beck (1971b, 1971c)
White pine	Illinois	Gilmore (1968)
Spruces and balsam fir	Northeast	Meyer (1929)
Spruces and balsam fir	Maine	Mount and Gore (1952)
Spruces and balsam fir	Newfoundland	Van Nostrand (1964), Page (1968)
Spruces and balsam fir	Quebec	Linteau (1955)
Spruces and balsam fir	Ontario	Payandeh (1974b)
Spruces and balsam fir	Saskatchewan	Payandeh (1974c)
Spruces and balsam fir	N. Michigan	Bowman (1941)
White and black spruces	Central and E. Canada	Heger (1968, 1969, 1971) Heger and Lowry (1971) Page and Van Nostrand (1971)
White spruce	Ontario	Stiell and Berry (1967, 1973a)
White spruce	Saskatchewan	Kabzems (1971)
White spruce	Lake States	Gevorkiantz (1957c), Ek (1976)
Red spruce	Maine	McLintock and Bickford (1957)
Black spruce	Minnesota	Fox and Kruse (1939), LeBarron (1948)
Black spruce	Lake States	Gevorkiantz (1957b)
Black spruce	Alberta	Horton and Lees (1961)
Black spruce	Saskatchewan	Kabzems (1953)
Black spruce	Manitoba and Saskatchewan	Jameson (1964)
Black spruce	Ontario and Quebec	Bedell *et al.* (1955), MacLean and Bedell (1955)
Balsam fir	Lake States	Gevorkiantz (1956c)
Jack, red, and white pines; white and black spruces; balsam fir; tamarack; white-cedar	Lake States	Lundgren and Dolid (1970)
White-cedar	Lake States	Gevorkiantz (1957a)
Tamarack	Lake States	Gevorkiantz (1957f)
Hemlock	New York, Michigan, S. Appalachians	Monserud and Ek (1976)

Table 2.--Site index curves for northern hardwood forest species

Species	Area	Reference
Sugar maple, yellow birch, white ash, paper birch	Vermont, New Hampshire	Curtis and Post (1962a), Solomon (1968)
Sugar maple, white ash	Vermont	Farrington and Howard (1958)
Sugar maple	Vermont	Hawes and Chandler (1914)
Sugar maple	New York	Farnsworth and Leaf (1963)
Sugar maple	N. Lower Michigan	Shetron (1972b)
Red maple	Connecticut and Massachusetts	Hampf (1965)
Beech	Northeast	Hampf (1965)
Sugar maple, yellow birch, beech, elm, basswood	Lake States	Monserud and Ek (1976)
Black cherry	New York	Hampf (1965)
Black cherry	N.W. Pennsylvania	Ward *et al*. (1965)
Paper birch	N. Wisconsin	Cooley (1958, 1962)
Q. Aspen and paper birch	Lake States	Lundgren and Dolid (1970)
Aspens	Lake States	Kittredge and Gevorkiantz (1929), Brown and Gevorkiantz (1934), Gevorkiantz (1956b)
Aspens	Lower Michigan	Graham *et al*. (1963), Zahner and Crawford (1965)
Aspens	N. Cent. Minnesota	Schlaegel (1971)
Aspens	Saskatchewan	Kirby *et al*. (1957)
Aspens	Alberta	Horton and Lees (1961)
Aspens	Newfoundland	Page (1972)
Aspen, paper birch, tolerent hardwoods	N. Ontario	Plonski (1960), Payandeh (1974a)
Q. aspen, paper birch	Alaska	Gregory and Haack (1965)
Quaking aspen	Rocky Mountains	Jones (1966, 1967), Jones and Trujillo (1975)

Site Index Comparisons Between Species

More intensive timber management requires the ability to select the most desirable tree species for each parcel of land. Should we, for example, choose from among several species of pine, or should we manage aspen on short rotations? On other areas should we consider favoring certain hardwood species for veneer and high value saw log production? Stands rarely have measurable trees of all species for which we need site index comparisons. But even when a stand does not contain the tree species for which site index estimates are desired, we can still estimate site index using the tree species actually present. Species comparison graphs can be used to convert site index of the species present to site index of the desired species. Unfortunately, only six site index comparison studies are available for northern forest species (table 3).

Table 3.--Site index comparisons for northern forest species

Species	Area	Reference
White pine; eastern hardwoods; shortleaf, pitch, and Virginia pines	S. Appalachian Mts.	Doolittle (1958)
White pine and red maple	N. Connecticut, W. Massachusetts, E. New Yrck	Foster (1959)
Northern hardwoods	Vermont	Curtis and Post (1962b)
Northern conifers and hardwoods	N. Minnesota	Carmean and Vasilevsky (1971)
Red, jack, and white pine	Upper Michigan	Shetron (1975)
Red pine and quaking aspen	N. Minnesota	Alban[a/]

[a/] Alban, D. H. 1976. U. S. Forest Service, North Cent. For. Exp. Stn. (unpublished manuscript).

Site index comparison graphs are most useful in areas having great ranges in soil and site, and where the forest manager has the problem of selecting the most desirable tree from among many alternative species. However, when selecting the most desirable tree species we should keep in mind that site index comparisons are merely that--comparisons of tree height at index age--and they are only the necessary first step in choosing the most desirable species for a particular site. We should also consider tree height growth before and after index age. And we should also compare both volume and value of wood produced in addition to comparing site index.

Growth Intercept

The growth intercept method uses a period of early height growth rather than long-term height growth as an index of site quality. The method was developed for conifers having distinct internodes marking annual height growth; usually the total length of the first 5 internodes above breast height is used an an index of site. Several growth intercept studies have been published for red and white pine (table 4). This method is particularly useful for areas where trees are too young for the usual 50-year site index curves. However, the method has the disadvantage of basing site quality estimation only on early height growth, and this may not be a very good indication of height growth in later years.

We need additional growth intercept studies for red and white pines in areas where existing studies may not apply. Futhermore, the method also might be applicable to jack pine, spruce, and larch, or even to hardwoods such as ash and maple. Internodes are not as distinct on these species, nevertheless, internodes still can be observed when trees are relatively young.

Table 4.--Growth intercept studies for estimating site quality of red and white pines

Species	Area	Reference
Red pine	New York	Ferree *et al.* (1958), Richards *et al.* (1962)
Red pine	Michigan and S. Ontario	Day *et al.* (1960), Schallau and Miller (1966), Gunter (1968)
Red pine	Wisconsin	Wilde (1964, 1965)
Red pine	N. Minnesota	Alban (1972a)
White pine	S. Appalachian Mts.	Beck (1971a)

Soil-Site Evaluation

The soil-site method has received more emphasis in the United States than other methods of indirectly estimating site quality (Carmean 1975), and many studies have been published for northern forest species in the United States and Canada (tables 5 and 6). This method is particularly useful for areas that vary greatly in soil and site, and where forest stands are usually not suited for direct measurements of site index, for example in unevenaged, poorly stocked, too young, or heavily cut stands.

The soil-site method relates soil, topography, and climate in a forest area to site index. Studies are made using many plots representing the range of site quality, soil, topography, and climate found within the area. Site index is estimated from the trees on each plot, and then multiple regression methods are used to relate site index to the associated soil, topographic, and climatic features. The resulting multiple regression equations are used to calculate tables and graphs for estimating site index in the field. Field foresters can easily measure the needed features which may include surface soil depth, texture, stone content, aspect, slope position, and slope steepness. The features found to be important in soil-site studies may differ depending on tree species, soil, topography, and climate of the area. So results are valid only for the particular study area, and for the soil and topographic conditions sampled within the study area. Except for the listed studies (tables 5 and 6) large gaps exist in our knowledge about soil-site relations of many northern forest species.

Plant Indicators

Understory vegetation has long been used for classifying forest site quality in northern Europe using methods first developed by Cajander (1926) in Finland. The method received considerable support in the early days of American forestry, and in Canada an active program of site classification developed following a visit by Ilvessalo (1929). Most plant indicator research for northern forest species has been done by Canadians (table 7) and several articles review its philosophy and methodology (Holman 1929, Kabzems 1951, Linteau 1953, Long 1953, Rowe 1956, Jurdant 1969, Jurdant et al. 1975, Burger 1972).

Table 5.--Soil-site studies for northern conifer forest species

Species	Area	Reference
Red pine	Connecticut	Haig (1929), Hicock et al. (1931)
Red pine	New York	Stone et al. (1954, 1958, 1962), Richards et al. (1962), Richards and Stone (1964), Dement and Stone (1968)
Red pine	Massachusetts	Mader and Owen (1961), Mader (1968)
Red pine	Lower Michigan	Van Eck and Whiteside (1958, 1963), Hannah (1969)
Red pine	S.E. Minnesota	Scott and Duncan (1958)
Red pine	N. Minnesota	Alban (1972b, 1974)[a]
Red pine	Quebec	Popovich (1975)
Red and jack pines	Lower Michigan	Hannah and Zahner (1970)
Red, jack, white pines; white and Norway spruce	Wisconsin	Wilde et al. (1951, 1964a, b, c, d, 1965), Wilde, Maeglin and Tanzer (1966), Wilde, Paul and Mikola (1951), Wilde, Tanzer and Trautmann (1963), Wilde (1970)
Red and white pines	S.E. Ohio, S. Indiana	Gaiser and Merz (1953)
Jack pine	N. Minnesota	Pawluk and Arneman (1961), Frissell and Hansen (1963)
Jack pine	N. Ontario	Chrosciewicz (1963)
White pine	Maine	Czapowskyj and Struchtemeyer (1958), Stratton and Struchtemeyer (1958)
White pine	S.E. New Hampshire	Husch and Lyford (1956)
White pine	New Hampshire	Barrett and Goldsmith (1973)
White pine	Massachusetts	Mount (1976)
White pine, spruces	Maine	Young et al. (1950), Young (1954), Mader et al. (1952)
White, red, Scotch pines	Vermont	Hannah (1971)
Northern conifers and hwds.	N. Minnesota	Bakuzis et al. (1962)
Northern conifers and hwds.	Quebec and Ontario	Bedell and MacLean (1952), MacLean and Bedell (1955)
Northern conifers and hwds.	Manitoba	Halliday (1935)
Black spruce	N. Minnesota	Heinselman (1963), Watt and Heinselman (1965)
Black spruce	Newfoundland to W. Ontario	Lowry (1964, 1970, 1975)
White spruce	Cent. Alberta	Duffy (1965)
Red and white spruce	Maine	Hoar and Young (1965)
Japanese and European larches	S. New York	Aird and Stone (1955)

[a] Also Alban, D. H. 1976. U.S. Forest Serv., North Cent. Forest Exp. Stn., (unpublished manuscript).

Table 6.--Soil-site studies for northern hardwood forest species

Species	Area	Reference
Sugar maple	Vermont	Post (1968), Post and Curtis (1970)
Sugar maple	N. Michigan	Westveld (1933)
Sugar maple	Pennsylvania	Nuss and Borden (1968)
White ash	N.W. Pennsylvania	Lewis and Ward (1967)
Black cherry	N.W. Pennsylvania	Davis and Ward (1966)
Yellow and paper birches	New England and Lake States	Post *et al.* (1969)
Paper birch	N. Wisconsin	Cooley (1962)
Quaking aspen	Minnesota and Wisconsin	Kittredge (1938), Stoeckeler (1948, 1960), Fralish and Loucks (1967)
Quaking aspen	N. Minnesota	Meyer (1956), Voigt *et al.* (1957) Strothmann (1960)
Quaking aspen	Cent. Wisconsin	Wilde and Pronin (1949, 1950)
Bigtooth aspen	Lower Michigan	Graham and Harrison (1955), Hannah and Zahner (1970)

In Canada plant indicators are mainly used to describe natural "ground vegetation types." As part of a broad land classification system, these types include forests believed to have similar trends in productivity, regeneration, and succession. For this reason these vegetation types might be managed using similar silvicultural practices. This system is useful for stratifying variable forest areas, but in most cases there is little factual evidence about how closely these vegetation types describe forest site quality.

The plant indicator method has been widely used in undisturbed northern coniferous forests because they usually have relatively few understory plant species, and plant communities are usually distinct and easily recognized. But our more southerly forests have often been repeatedly disturbed, and the numerous understory species usually occur as a continuum rather than discrete communities. Nevertheless, plant indicators can supplement other methods of site estimation and forest land classification, despite the complexities and shortcomings of the method.

Physiographic Site Classification

Forest land classification programs in Canada have been in progress for many years (Lacate 1966, Burger 1972) and were initially based on the understory vegetation methods of Cajander. Following World War II, aerial photographs became an important tool in "forest site" mapping (Losee 1942a, 1942b, Hills 1950, Burger 1957, Jurdant 1964b). As a result landforms have become prominent in forest land classification because they are easily identified on aerial photos. The most widely used method of physiographic site classification was developed in Ontario (Hills 1952, 1953, 1954, 1958, 1960, 1961, Hills and Pierpoint 1960, Pierpoint 1962, Brown 1953, Farrar 1960). Using this method Ontario was subdivided hierarchically into site regions, landscapes, land types, and sites. Variations of this method also have been used in other Canadian provinces where northern forest species occur (Wilde, Voigt, and Pierce 1959, Bedell and MacLean 1952, Bedell, Brown, and MacLean 1953, Bedell, MacLean, and Brown 1955, MacLean and Bedell 1955, Duffy 1965, Duffy and Nemeth 1967, Knight and Duffy 1967, Loucks 1962).

Table 7.--Plant indicator studies for estimating site quality of northern forest species

Species	Area	Reference
Jack pine	Saskatchewan	Kabzems and Kirby (1956)
Jack and red pine	Manitoba	Ritchie (1961)
Jack pine and black spruce	Manitoba	Mueller-Dombois (1964, 1965)
White pine	New Hampshire	Hazard (1937), Stanley (1938)
White pine	Wisconsin	Gevorkiantz and Zon (1930)
White pine	Great Lakes and St. Lawrence Valley	Horton and Brown (1960)
Spruce-fir	Adirondack Mts of New York	Heimburger (1934)
Spruce-fir, Northern hwds.	Adirondack Mts, Vermont, N. Hampshire, W. Maine	Westweld (1951, 1952, 1953, 1954)
Spruce-fir, Northern hwds.	Lake Edward, Quebec	Sisam (1938a), Heimburger (1941), Ray (1941, 1956)
Spruce-fir, pines, hwds.	Lake States	Anon. (1930)
Spruce-fir, pines, hwds.	Quebec, Ontario, Saskatchewan	Losee (1942a, 1942b)
Spruce-fir, pines, hwds.	Manitoba, Saskatchewan	Rowe (1956)
Spruce-fir	Newfoundland	Damman (1964), Page (1970a, 1970b)
Spruce-fir	Quebec	Linteau (1940, 1953, 1955), Bellefeville (1932), Lafond (1958, 1960, 1964)
Black spruce	N. Minnesota	Heinselman (1963)
Black spruce	Newfoundland to W. Ontario	Vallée and Lowry (1970, 1972)
White spruce plantations	Quebec	Gagnon and MacArthur (1959)
N. hwds. and oaks	Connecticut	Hicock *et al*. (1931)
N. hwds.	Upper Michigan	Wilde and Scholz (1934)
Quaking and bigtooth aspens	Petawawa, Ontario	Sisam (1938b)
Quaking aspen	Minnesota, Wisconsin	Kittredge (1938)
Quaking and bigtooth aspens, jack pine	Michigan	Hellum and Zahner (1966)

In boreal forest portions of Quebec attempts were made to relate physiographic methods to the Braun-Blanquet plant sociological methods (Jurdant 1964a, 1964b, 1969, Jurdant and Roberge 1965, Jurdant et al. 1975); similar methods have been proposed for the northern Rocky Mountains (Layser 1974). In floristically richer portions of southern Quebec the Zürich-Montpellier sociological methods were combined with physiographic site classification methods (Lemieux 1963). Physiographic site classifications also were included with the nationwide Canada Land Inventory for the agricultural portions of Canada (McCormack 1966, 1967, 1968, Lowe et al. 1972). A "Land Systems Inventory" based on physiographic features also has been proposed for the western United States (Wertz and Arnold 1975).

Hills considers his physiographic method a "total site" classification, and defines site as "an integrated complex of climate, relief, geological material, soil profile, ground water, and communities of plants, animals, and man". Thus, his methods are "holistic" (Burger 1972), paralleling the "ecosystem" viewpoint (Rowe 1953, Rowe et al. 1960). This broad ecological viewpoint differs from the specific site quality viewpoint in which quantitative values of site index and yield are used for classifying forest land productivity.

The physiographic site methods for forest landscape classification provide a good framework for stratifying large inaccessible forest regions into broad subdivisions based on general features of climate, landform, soil and vegetation. However, in most cases relatively little quantitative data is given regarding site quality for forest trees or for the range of site quality that is included within each physiographic subdivision. The physiographic system involves much subjective judgement and intuition, and considerable research is needed to provide the needed site quality information.

Soil Surveys

Soil surveys of agricultural land in the United States have been made for more than 75 years, but only in recent decades have forested lands been surveyed using modern methods of the National Cooperative Soil Survey. Soil survey reports often contain tables listing site index averages for soil mapping units, or for various "Woodland Suitability Groups". Several soil-site and other publications list site index averages for northern forests species using soil survey classification units (table 8).

How reliable are soil survey mapping units for estimating forest site quality? Unfortunately, in many areas most of the mapping units have similar site indexes, even though site index may vary widely within each soil mapping unit. Probably much of the site variation within soil units is due to certain soil and topographic features that are important for tree growth, but that are not well described in soil unit definitions. For example, surface soil depth, subsoil texture, aspect, slope position, and slope steepness are features often closely related to site quality, but these features may vary widely within definitions for certain soil mapping units. If such important site quality features are not well defined or are not included in soil unit definitions, then excessive site variation within the soil unit can be expected.

Table 8.--Site index of northern forest species in relation to soil survey classification units

Species	Area	Reference
Red pine	Connecticut	Hicock *et al.* (1931)
Red pine	Massachusetts	Mader (1968)
Red pine	New York	Richards and Stone (1964), Dement and Stone (1968)
Red pine	Lower Michigan	Van Eck and Whiteside (1958, 1963)
Jack pine	N. Cent. Minnesota	Pawluk and Arneman (1961)
Jack and white pines, aspen, northern hwds., oak	Lake States	Roe (n.d., 1935)
Jack, red, white pines; quaking aspen	N. Wisconsin	Stevens and Wertz (1971)
Jack, red, white pines	Upper Michigan	Shetron (1975)
Jack pine, red oak, sugar maple, bigtooth aspen	Upper Michigan	Shetron (1969, 1972a)
Northern hwds. and conifers	E. New York	Diebold (1935)
Northern hwds.	Vermont	Post and Curtis (1970)
Sugar maple	Vermont	Farrington and Howard (1958)
Sugar maple	New York	Farnsworth and Leaf (1963)
Sugar maple	N. Michigan	Westveld (1933)
Quaking aspen	Minnesota and Wisconsin	Kittredge (1938), Stoeckeler (1960)

Classification systems for soil surveys are flexible and provide an excellent framework for the addition of soil phases or other soil and topographic subdivisions needed for more accurately defining site quality--if the requisite soil-site information is available. This information can be provided by soil-site studies that pinpoint the various soil and topographic features closely related to tree growth, and that also express the magnitude of site change associated with each important site features. Some soil-site studies are already available for northern forest species (tables 5 and 6), but for many localities we lack this necessary information.

COMPLEMENTARY FRAMEWORK FOR SITE, YIELD, AND FOREST LAND CLASSIFICATION

The sheer volume of literature for the many methods of site quality estimation, yield prediction, and forest land classification may at first glance seem confusing, and in some cases, even contradictory. But this confusion is more apparent than real because these fields are in many ways complementary rather than contradictory. All have a common goal--to determine and classify the productivity of land for tree growth. Accordingly, in the future we should not remain separated in mensurational, soil, and ecological lines, but instead we should try to coordinate the various methods for estimating site quality, predicting timber yields, and classifying forestlands (fig 1).

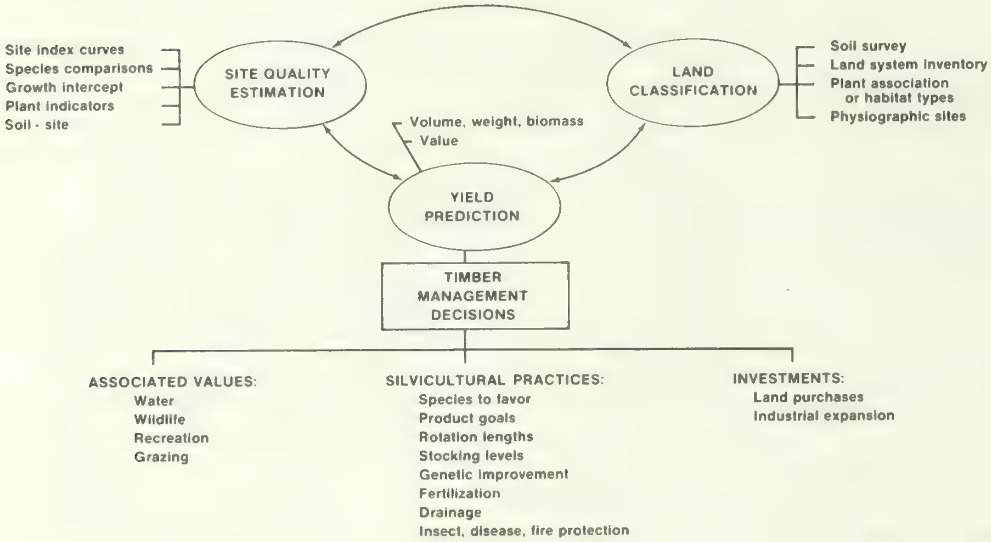

Figure 1.--Decisions about intensive timber management depend upon a complimentary framework of site quality estimation, yield prediction, and forest land classification.

All of us are dealing with separate parts of the overall problem of determining forest land productivity, and regardless of where we begin we eventually will arrive at each of the other important parts. Those concerned with local estimation of site quality will eventually strive to classify site for the entire area, and they also will need to convert site index estimates into yield estimates. Those concerned with yield prediction eventually will need means for determining both local site quality and yield, as well as site and yield estimates for the entire area. And those concerned with forest land classification will eventually need both site and yield estimates for their classification units. Each of these three major areas--site quality estimation, yield prediction, and forest land classification--have major contributions to make because intensive timber management of the future will hardly be possible without a closer coordination of all disciplines.

How can we coordinate these three major fields? First of all we should recognize that we already have considerable scattered information about site quality, yield, and forest land classification (tables 1 to 8). For any specific area we should gather this information and then determine how much is accurate, applicable, and useful. If information is lacking, is not applicable, or is too general for intensive timber management, we should make the appropriate studies to get this needed information.

Site Quality Estimation

Our goal should be to estimate site quality for all portions of a forest area regardless of the character and condition of existing forest cover. Site index can be directly measured in the few areas having suitable trees. For other areas we might be able to extend site estimates using species comparison graphs or growth intercepts. And plant indicator and soil-site methods can be used for the remaining areas where no suitable trees can be found for direct site index measurements.

Yield Predictions

Site index estimations for local stands, or for the entire forest area, are only estimates of tree height at the 50-year index age. Site index is a qualitative index of relative forest land productivity, and merely ranking areas on the basis of height at index age is not enough. We also must be able to convert site index estimates into quantitative values for timber growth and yield. This can be done if adequate yield tables are available for the many tree species, stocking levels, and sites found in northern forest areas. However, before these yield tables can be applied we must have means for estimating site quality for each local stand as well as for the entire forest area. Accordingly, both site estimation and yield prediction methods should be viewed as complementary fields both of which are needed to attain our overall goal of predicting productivity for forest lands.

Forest Land Classification

Each of the various methods of estimating site quality and yield are still only point estimations regardless if we use trees, understory vegetation, or soil-site features. Still to be resolved is the problem of abstracting point observations into a site and yield classification for the entire landscape. Such site classifications can be made for the entire area if detailed forest land surveys are available that use mapping units known to be closely related to site quality and yield.

Unfortunately forest land surveys are usually made using "basic" soil, physiographic, or vegetal mapping units defined by soil scientists or ecologists. After the survey is completed, attempts might then be made to interpret the survey in terms of the site quality and timber yield associated with each mapping unit. At this time it may be discovered that site quality and yield vary so much within mapping units that only very broad and general conclusions are possible. But more accurate and usable mapping units could have been achieved if, prior to the survey, factual soil-site information had been used to define mapping units that included the specific soil, topographic, and climatic features known to be closely associated with forest site quality. This requires coordinated research efforts to acquire factual soil-site information prior to the survey rather than after the survey has been finished. And such coordinated research requires the knowledge and skill of mensurationists, soil scientists, ecologists, and foresters as well as cartographers capable of using aerial photographs and other remote sensing techniques.

USING SITE, YIELD, AND FOREST LAND CLASSIFICATION FOR INTENSIVE TIMBER MANAGEMENT

How can the inventory of site information (tables 1-8) and the complimentary framework (fig. 1) help us practice more intensive timber management?

One of the first steps is to map and stratify the landscape into categories of management intensity. Usually the superior sites will be managed most intensively, less productive sites will be managed less intensively, and the poorest sites will receive little or no management, or perhaps will be designated for other land uses.

Next, decisions must be made about what silvicultural practices are appropriate for each site shown on our landscape classification. We know that thinning, fertilization, drainage, and other silvicultural practices can be very effective for certain species and sites. However, we often are not certain about the specific sites and soils where these practices should be applied or, further, how intensively these practices should be applied on each site. Because growth responses differ on different sites we must have growth and yield information for all sites so that estimates can be made of the increased growth achieved by applying each silvicultural practice. And knowing growth responses from silvicultural practices on each site we then can estimate costs and benefits associated with the various practices employed in intensive forest management.

Likewise, decisions about land acquisition and industrial investments also require specific knowledge about site quality and about timber growth and yield. Such knowledge enables a manager to weigh the costs of these investments against the anticipated additional growth, yield, and income to be derived from the intensively managed forest. A further consideration is that compromises and restrictions on timber management might be needed because of other associated values (water, wildlife, recreation, grazing) and such compromises may decrease timber yields. Accordingly, we need specific knowledge about site and yield so that we can estimate the amount of these growth reductions, and hence the economic costs, resulting from such compromises.

In addition to timber values, forest land also has values for water, wildlife, recreation, and grazing. Managing land for these values requires much the same information as for timber--soil, topographic, and climatic data. Accordingly, for each of these associated values we could reason, as we have done for timber (fig. 1), that a coordinated approach is needed for local site estimation, yield prediction, and land classification. In many cases we may find that land features associated with timber site quality and yield may also be important in determining yields for these other associated values. If so, forest land classification for timber might be integrated with land classification for these other values resulting in a multiple use forest land classification.

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Appendix: Common and scientific names of tree species (Little 1953)

Common name	Scientific name
Balsam fir	*Abies balsamea* (L.) Mill.
Red maple	*Acer rubrum* L.
Sugar maple	*Acer saccharum* Marsh.
Yellow birch	*Betula alleghaniensis* Britton
Paper birch	*Betula papyrifera* Marsh.
American beech	*Fagus grandifolia* Ehrh.
White ash	*Fraxinus americana* L.
European larch	*Larix decidua* Mill.
Tamarack	*Larix laricina* (Du Roi) K. Koch
Japanese larch	*Larix leptolepis* Murr.
Norway spruce	*Picea abies* (L.) Karst.
White spruce	*Picea glauca* (Moench) Voss
Black spruce	*Picea mariana* (Mill.) B.S.P.
Jack pine	*Pinus banksiana* Lamb.
Shortleaf pine	*Pinus echinata* Mill.
Red pine	*Pinus resinosa* Ait.
Pitch pine	*Pinus rigida* Mill.
Eastern white pine	*Pinus strobus* L.
Scotch pine	*Pinus sylvestris* L.
Virginia pine	*Pinus virginiana* Mill.
Bigtooth aspen	*Populus grandidentata* Michx.
Quaking aspen	*Populus tremuloides* Michx.
Black cherry	*Prunus serotina* Ehrh.
Northern red oak	*Quercus rubra* L.
Northern white-cedar	*Thuja occidentalis* L.
American basswood	*Tilia americana* L.
Eastern hemlock	*Tsuga canadensis* (L.) Carr.

NUTRIENTS : A MAJOR CONSIDERATION IN INTENSIVE FOREST MANAGEMENT

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Abstract

Estimates of nutrient losses are compared for a stem-only harvest versus a whole-tree harvest of a clearcut northern hardwood stand. Combined nutrient losses due to increased leaching and removal of vegetation after stem-only harvesting are estimated to be 334 kg/ha for calcium and 265 kg/ha for nitrogen. For a whole-tree harvest, combined losses are estimated at 537 kg/ha for calcium and 486 kg/ha for nitrogen. Replenishment of available calcium and nitrogen could be a problem, depending upon the rate of soil mineralization and natural replacement.

THE NUTRIENT CAPITAL of the forest ecosystem is a main concern in intensive management. In some cases the concern is that nutrients are lacking and additions are needed to promote additional growth and more rapid growth. In other cases concern is about the nutrients lost from a site through physical removal by harvesting and by basic changes in the nutrient cycle after harvesting.

Conceptual models for fluxes of major nutrients in forest ecosystems are now commonplace. In some cases these models are detailed; J. Melillo at Yale University (personal communication) defines 25 different compartments and numerous interrelated pathways for nitrogen flow into, within, and out of a northern hardwood forest. Less commonplace are quantitative values for the many compartments of forest nutrient cycles.

There are obvious reasons why we need quantification of the nutrient cycle. Intensive management can mean shorter rotations and more complete utilization and thus a greater drain of nutrients in harvested products. We need to know what this means in relation to overall nutrient capital and productivity of the managed site.

Harvesting the forest can also increase nutrient losses by leaching. The magnitude and importance of leaching losses will be greater for the more complete and more frequent harvests likely to accompany intensive management. Nutrients lost through leaching represent a drain on nutrient capital as well as a source for increasing the nutrient concentrations of streams and groundwater. With implementation of the Federal Water Pollution Control Act Amendments of 1972, nutrient leaching from silvicultural activities has gained recognition as a potential source of water pollution, furthering the need for quantifying leaching losses.

Information about nutrient leaching and removal by harvesting is limited. To my knowledge, only four studies have been made in the eastern United States and eastern Canada on the problem of nutrient removal in harvested trees (Jorgensen et al. 1975; White 1974; Boyle et al. 1973; Weetman and Webber 1972). More information is available about leaching of nutrients to streams (Corbett et al. 1975; Hornbeck et al. 1975a, 1975b; Aubertin and Patric 1974; Pierce et al. 1972, 1970; Verry 1972; Johnson and Swank 1973; and Stone 1973). But the research on nutrient leaching is still at a stage where it is generating more questions than answers.

In this paper I will apply information from the above and other studies to demonstrate some potential impacts of forest harvesting on nutrients and the nutrient cycle. This demonstration requires considerable extrapolation of various types of data, but serves to show the extent of our knowledge about relationships between intensive management and nutrients in northern types.

METHODS

For this demonstration I will consider two nutrients, calcium and nitrogen. Both are important ecologically in forest ecosystems, and both may undergo increased leaching after forest harvesting.

For a forest type I have chosen northern hardwoods (beech, birch, and maple mixture) because of the available information and data, and because large areas of the Northeast are covered by this type. Species composition and size classes are taken from a

90-year-old stand at the Bartlett Experimental Forest in central New Hampshire. On this area of 2.5 hectares, all trees over 2.5 cm dbh were measured (data provided by S. M. Filip, Northeastern Forest Experiment Station, Durham, N. H.).

To estimate nutrient removal by various intensities of forest harvesting, both biomass values and nutrient content of plant tissues are needed for individual components of the forest stand. Biomass values were obtained by using a dimensional analysis of a northern hardwood stand at the Hubbard Brook Experimental Forest in central New Hampshire (Whittaker et al. 1974). Diameter at breast height is used as an independent variable in a series of linear regression equations. The equations provide estimates of biomass for stem wood, stem bark, branch wood, and current leaves and twigs by individual species.

Nutrient content of these components was determined by using chemical analyses of plant tissues made at Hubbard Brook by Likens and Bormann (1970). These analyses provide nitrogen and calcium values as a percentage of biomass. Weight of nutrients in each component is estimated simply by multiplying biomass by the percentage of calcium or nitrogen.

RESULTS

Using data from the northern hardwood stand at Bartlett Experimental Forest and applying the equations from Whittaker et al. (1970), I found that total biomass in trees >2.5 cm dbh is 203 metric tons/ha (table 1). Of this total, stem wood comprises 64 percent, stem bark 7 percent, branches 27 percent, and current leaves and twigs 2 percent. By species, 34 percent of the biomass is maple, 32 percent birch, and 24 percent beech. White ash, red spruce, and eastern hemlock make up the remaining 10 percent.

Multiplying biomass by the nutrient contents of individual components of biomass (Likens and Bormann 1970), I find that total calcium and nitrogen in trees >2.5 cm dbh is 547 kg/ha and 483 kg/ha, respectively (table 2). For calcium, 229 kg/ha or 42 percent of the total in trees is bound in branches and 193 kg/ha or 35 percent of total is bound in stem bark. Stem wood contains 99 kg/ha or 18 percent, and current twigs and leaves contain only 25 kg/ha or 5 percent of the total. By species, 36 percent of the calcium total in trees

Table 1.--Dry weight of biomass, in metric tons per hectare

Species	Stem wood	Stem bark	Branches	Current leaves and twigs	Total	
	------Metric tons per hectare-------					Pct.
Beech	31.82	2.18	13.19	1.08	48.27	24
Yellow birch	26.76	3.24	14.36	.80	45.16	22
Paper birch	11.25	1.29	6.79	.31	19.64	10
Sugar maple	2.41	.31	.59	.08	3.39	2
Red maple	43.80	5.33	13.85	1.13	64.11	32
White ash	3.10	.20	1.37	.07	4.74	2
Red spruce	.45	.07	.12	.01	.65	0
Eastern hemlock	11.46	1.42	3.66	.14	16.68	8
Total	131.05	14.04	53.93	3.62	202.64	
Percent	64	7	27	2	--	--

is in maples, 30 percent in birches, and 26 percent in beech.

For nitrogen, 195 kg/ha or 40 percent of the total is in branches and 81 kg/ha or 17 percent is in stem bark (table 2). Stem wood contains 126 kg/ha or 26 percent and leaves and twigs contain 80 kg/ha or 17 percent of the nitrogen total. By species, 38 percent of the nitrogen total in trees is in birches, 32 percent in maples, and 24 percent in beech.

Only minor portions of biomass and nutrients are in trees that might be considered too small to harvest. For the Bartlett stand, trees less than 10 cm dbh contain only 3 percent of the total biomass, 2 percent of the total calcium in vegetation, and about 3 percent of the total nitrogen in vegetation.

DISCUSSION

The above data can be used to compare nutrient removal for differing harvests. An illustration is clearcutting to harvest stems only versus clearcutting for whole-tree harvest. For the Bartlett stand, Table 2.--Calcium and nitrogen in biomass

Species	Stem wood	Stem bark	Branches	Current leaves and twigs	Total	
	kg per hectare					Pct.
			CALCIUM			
Beech	19.2	55.2	62.0	6.4	142.8	26
Yellow birch	16.5	31.1	60.3	7.1	115.0	21
Paper birch	7.0	12.4	28.5	2.8	50.7	9
Sugar maple	2.5	4.4	2.6	0.5	10.0	2
Red maple	45.0	75.2	59.6	7.2	187.0	34
White ash	1.9	5.0	6.5	0.4	13.8	3
Red spruce	0.3	0.5	0.3	0.1	1.2	0
Eastern hemlock	6.9	9.6	9.2	0.4	26.1	5
Total	99.3	193.4	229.0	24.9	546.6	
Percent	18	35	42	5	--	--
			NITROGEN			
Beech	35.1	16.4	39.6	22.7	113.8	24
Yellow birch	24.7	19.4	63.2	21.0	128.3	26
Paper birch	10.4	7.8	29.9	8.1	56.2	12
Sugar maple	2.4	1.7	2.2	1.8	8.1	2
Red maple	42.9	29.3	51.3	23.7	147.2	30
White ash	3.4	1.5	4.1	1.5	10.5	2
Red spruce	0.3	0.2	0.1	0.1	0.7	0
Eastern hemlock	6.3	5.0	5.0	1.6	17.9	4
Total	125.5	81.3	195.4	80.5	482.7	
Percent	26	17	40	17	--	--

combined stem wood and bark contain a total of 293 kg/ha of calcium and 207 kg/ha of nitrogen (table 2). All components, including stems, branches, leaves, and twigs, contain 547 kg/ha of calcium and 483 kg/ha of nitrogen. Thus a whole-tree harvest has potential for removing about 1.9 times as much calcium and about 2.3 times as much nitrogen as a stem-only harvest.

For any harvest, some residual materials and their incorporated nutrients will be left on the site. For the comparison of the two clearcuttings mentioned above, both harvests were assumed to be about 80 percent efficient--or that 20 percent of the harvestable materials were left on the site. Thus for the Bartlett stand, harvesting stems only would remove an estimated 234 kg/ha of calcium and 165 kg/ha of nitrogen (table 3). A whole-tree harvest is estimated to remove about 437 kg/ha of calcium and 386 kg/ha of nitrogen.

Nutrient losses also occur as a result of increased leaching in the several years immediately after harvest. From several studies in central New Hampshire (Pierce et al. 1970; Hornbeck et al. 1975a and 1975b), I have estimated leaching losses from the Bartlett stand to be increased about 100 kg/ha for both calcium and nitrogen (table 3). Thus combined losses from a stem-only harvest are 334 kg/ha for calcium and 265 kg/ha for nitrogen. For a whole-tree harvest, combined losses are estimated at 537 kg/ha for calcium and 486 kg/ha for nitrogen.

Table 3.--Soil nutrient capital and losses due to clearcuttings in which 80 percent of product is removed

Nutrient losses and reserves	Calcium	Nitrogen
	-------kg per hectare---------	
Losses due to:		
Stem-only harvest	234	165
Whole-tree harvest	437	386
Leaching losses	100	100
Total losses:		
Stem-only harvest	334	265
Whole-tree harvest	537	486
Soil reserves:		
Bound	6,000-20,000	6,000-8,000
Available	500-1,000	25-250

One means of evaluating the losses is to compare them with nutrient content of the forest soil (table 3). For soils similar to those at Bartlett, total bound calcium is estimated between 6,000 and 20,000 kg/ha, and available calcium is estimated between 500 and 1,000 kg/ha. Corresponding estimates for nitrogen are 6,000 to 8,000 kg/ha bound and 25 to 250 kg/ha available. When compared with the total reserves in the soil, the calcium and nitrogen losses from either stem-only or whole-tree harvests are relatively small. However, in the case of nitrogen, of which the soil reserves are smaller, combined losses from stem-only harvesting may represent 3.3 to 4.5 percent of the bound nitrogen in the soil, and losses from whole-tree harvesting may represent 6.1 to 8.1 percent.

The above evaluations are in terms of total nutrient reserves in the soil. Important concerns also include how much of the losses come from the pool of nutrients readily available for plant use, and how fast such losses are replenished. Most of the increased losses to leaching probably come from the available pool. This could mean that as much as 20 percent of the available calcium and much of the available nitrogen could be lost to leaching (table 3).

Replenishment of the available pool could be a problem for both calcium and nitrogen. Although there were large calcium reserves bound in rocks and soils, the conversion to available calcium is slow (Johnson et al. 1968). In previous studies, Boyle et al. (1973) and Weetman and Webber (1972) both projected the depletion of calcium as being potentially the first adverse consequence of whole-tree harvesting. In the case of nitrogen, there is little, if any, input from rock-weathering; so most available nitrogen must come from soil mineralization. Both nitrogen and calcium are supplied to the available pool through precipitation, but the amounts are relatively small. At Hubbard Brook, the annual additions in precipitation average 2.2 kg/ha for calcium and 6.5 kg/ha for nitrogen.

Replenishment of nutrients may become a more significant problem if rotation age is reduced. Most northern forest types are currently on 50- to 100-year or longer rotations, thus providing a good opportunity for natural replacement of nutrients. Intensive management and improved utilization could shorten rotations to 30 years or less. The possibility of shorter rotations further emphasizes the need for information about rates and methods by which nutrients are made available for plant use, both before and after harvesting.

There are options that may reduce the loss of nutrients due to harvesting. An example for whole-tree harvesting: avoid removing leaves, either by harvesting in the dormant season or by felling trees well in advance of skidding so that senescence and leaf fall occur on site. Such an action for the Bartlett stand could reduce calcium removal by 25 kg/ha and nitrogen by 80 kg/ha (table 2). Configuration of the harvest can also affect nutrient losses. After a Hubbard Brook watershed was clearcut progressively in strips, nutrient losses to leaching were one-third to one-half less than those from nearby watersheds that were cut in large blocks (Hornbeck et al. 1975b).

In addition to the gross nutrient losses discussed above, forest harvesting can have other more subtle impacts on the nutrient cycle. For example, the removal of hydrogen ions by exchange in the forest canopy (Eaton et al. 1973) may lessen the impact of acidic precipitation that occurs in the Northeast (Likens and Bormann 1974). The important chemical changes that occur as precipitation passes through the canopy raise the question of what may happen when the forest canopy is removed. In an earlier study at Hubbard Brook, in which a previously forested watershed was devegetated for a 3-year period, the stream water pH decreased from 5.1 to 4.3 (Likens et al. 1970). This change represents about a fivefold increase in hydrogen-ion content of stream water. There were many complex changes in the chemical composition of the stream as a result of devegetation. However, the absence of hydrogen-ion exchange in the canopy may have contributed to the increased acidity of stream water after vegetation was eliminated.

As another example, recent studies at Hubbard Brook indicate that nitrogen is fixed in northern hardwood stands at an estimated rate of 1 to 11 kg/ha/yr (personal communication, Joann Roskoski, Yale University). Practically all the fixation occurs in rotting wood, especially in material greater than 2 cm diameter. More intensive harvesting may leave less of this material on the site and eliminate much of the substrate for future nitrogen fixation.

Both the gross and subtle impacts on nutrients must be considered in attempts to harvest greater quantities of wood from northern forest types. Cooperation is needed between the manager and the researcher in quantifying the changes in nutrient cycles and in implementing practices that will conserve nutrients on the site.

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STATUS OF GROWTH AND YIELD INFORMATION FOR NORTHERN FOREST TYPES

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Abstract

Existing regional growth-and-yield information for most of the northern forest types is summarized by species. Present research is concentrated on growth-simulation models, constructed by either aggregating available information or through individual tree growth studies. A uniformity of more refined measurements is needed so that future growth models can be tried for other species and forest types.

MOST FOREST-MANAGEMENT decisions include some form of growth information, because cultural treatments on different sites cause growth responses to vary. Growth data are not only some of the most sought after information, but also are some of the most difficult to obtain. In order to report on the status of growth and yield information in northern forest types, it is necessary to realize that different forest types are comprised of many species within that type and that each species grows at a different rate. Each species has its own growth rate in height and diameter; and these rates depend directly upon site, moisture, and competition.

DESIRED GROWTH AND YIELD INFORMATION

The information desired most frequently would be used to predict the long-term influence of site, stand density, and silvicultural systems on the growth and yield of different stands in terms of product objectives. The long-term growth and yield predictions are desired for managed and unmanaged stands growing on different sites for varying periods of time.

Yield information is also needed for different silvicultural treatments used for different management objectives. In addition to different growing conditions, one needs knowledge of yields by product classes, including various portions of whole trees. Thus for growth and yield information to be meaningful, different aspects of tree growth--from fiber production to high quality sawlogs--must be considered. These products should be described within a framework of growing conditions and time requirements needed to achieve the desired product or measurement classes.

AVAILABLE GROWTH AND YIELD INFORMATION

Classical growth information has been developed for diameter and volume growth measured at 4.5 feet above ground, or volume growth of the whole bole by age classes.

The growth information available is primarily stand growth over an average set of conditions, usually for a relatively short period of time. This seems logical because it is impossible to collect data from various aged stands, with different silvicultural treatments, growing on different sites.

Existing yield tables are of two types. Normal tables, based on unmanaged stands at maximum or full stocking, show yields attained at various stand ages. The other type is empirical tables, which are constructed over the life of the stand, representing average stocking that may have varied greatly at different periods.

Normal tables are poor indicators of attainable product yields from thinned stands, while empirical tables do not give accurate estimates for long-term conditions unless stands are grown under the same conditions as those on which the tables were based. Yield information available gives harvest volume by age class and frequently by site index or class.

The major northern forest types recognized by the Society of American Foresters (1954) are: aspen-birch-pin cherry; white pine; swamp conifers; spruce-fir; and northern hardwoods. As a means of reviewing existing literature, I will discuss the growth and yield information for each of these forest types. This review of growth and yield information is not complete, and it is not intended to include all available sources of information. My purpose is to try to report the most recent or the most significant literature dealing with growth and yield in the northern forest types.

Within the aspen-birch-pin cherry type, almost pure stands of individual species occur. Therefore I will review existing growth and yield information by each species. For birch in New England, early information is available from Dana (1909) for natural uneven-age stands. Height, diameter, and volume growth are given by age and regeneration classification. Yield is given by age and quality class.

Diameter growth data for young managed birch crop trees with different degrees of thinning are presented by Solomon and Leak (1969). Merchantable volume yields are also given for even-age stands of various mean diameters and the number of years to reach that mean stand diameter by site index for managed and unmanaged stands. Normal yield tables for birch stands in the Midwest were reported by Plonski (1956); these tables give yield by site class, age, height, diameter, number of trees, and basal area. The same information for well-stocked aspen stands is presented in a similar manner. Information about aspen stands in the Midwest is given by Schlaegel (1972). He presents net periodic annual basal-area growth by age and stand density. Also, yield information is presented by age, site index, thinning regime, and stand density.

For white pine in New England, we have yield information for well-stocked stands (Frothingham 1914), and for old-field plantations for different locations by age and site index. The most recent yield information is given by Leak and others (1970) for white pine in New England related to age, site, and stocking. Although this and other yield information are available for white pine, extensive stand-growth information does not seem to be available. What growth information is available in the literature is for specific areas and is not presented by alternative management criteria.

For natural stands of red pine in the Lake States, extensive growth information by age, site index, and stand density are available (Buckman 1962). His tables present basal area, net growth, cubic feet, cordwood, and board-foot growth by site index, age, and stand density. Yield information is also presented, by site index, age, and stand density for various residual thinning densities.

Yield information for jack pine in the Lake States, along with cordwood growth and basal-area growth after thinning, is available by site and age (Eyre and

LeBarron 1944). Gevorkiantz (1947) published yield information with growth rates by size class and conversions for less-than-normal stocking. Later, normal yield tables for jack pine in northern Ontario were developed by Plonski (1956). Therefore, tables by site and age are available for a wide range of stand densities and varying silvicultural treatments.

Since the Lake States have stands of predominately black spruce with a low mixture of other spruce species black spruce will be discussed separately. The growth and yield of black spruce in the Lake States is available for managed stands by age, site, and basal-area density (Perala 1971). From these data, equations have been developed for estimating growth and yield for both cubic feet and cords. Also, normal yield tables are presented by site and age (Plonski 1956). Diameter growth by stocking and size class, and basal-area growth for various residual stand densities of the swamp conifers, are also available (Skilling 1959).

In addition to black spruce information, stand volume growth, and yields by age, site, and competition indices are available for balsam fir (Gevorkiantz and Olsen 1950). Growth and yield information for spruce and fir stands in the Northeast started in 1917 with Murphy's (1917) work on old-growth and old-field red spruce. This work included diameter growth by size and stand type for different locations throughout the Northeast. It also contained basal-area growth by age and quality class.

In the Northeast, both normal yield tables by Meyer (1929) and empirical yield tables by Westveld (1953) are available for spruce-fir stands. The normal tables are by age and site index for different species. The empirical tables are given by age, using a density and stand-composition index.

Average cubic-foot stand growth rates for spruce-fir stands have been presented for New England (Safford 1968). The averages are presented by density, height, and type of stand mixture. Yield information is presented by Merrill and Hawley (1924) for hemlock stands in southern New England. Cubic-foot and board-foot measures, and current annual and mean annual increments, are given by age and quality class. A more recent publication by Baskerville (1965) has given production of balsam fir stands in New Brunswick in both cubic feet and weight for different tree components for varying number of stems per acre.

Growth information for northern hardwoods began with diameter, height, and volume growth for stands in the Lake States and yield information for the Northeast (Hawes and Chandler 1914; Frothingham 1915). Both the growth and yield information is for fully-stocked stands by age and site differentiation.

Later additional normal yield information was presented by Spaeth (1920) and Gevorkiantz and Duerr (1937). These provide yields by age and site classifications for both the Lake States and New England northern hardwoods.

Yields for managed stands in New England have been combined and presented by Leak, Solomon, and Filip (1969). Their tables make use of existing information, both published and unpublished, for northern hardwood stands and present the number of years required to reach a specified yield by site index. Growth information for stands under different forms of management is given by Erdmann and Oberg (1973). Also Solomon [in press] has compiled stand growth responses for northern hardwoods in New England, by size class for different densities in uneven-age stands.

It becomes apparent from the partial listing of existing growth and yield information that much work has been done. Hence arises the question of "Why do we need more?" Why not just revise or adjust existing information?

FUTURE GROWTH AND YIELD INFORMATION

The general comparison of the desired growth and yield information with the actual published information indicates the intensive need for data, especially for managed stands. Since no two stands are alike, the need arises for the forest manager to have separate growth and yield information for stands of different species composition growing under different levels of stocking.

Stand information is usually based on average growth and yields over a large area. A broad average usually ignores many of the differences between individual stands. Thus one of the functions a land manager has is to determine how close his stands are to the reported average conditions.

Therefore, to estimate future growth rates and yields accurately and make meaningful forest-management decisions, the land manager needs information about the response of his stands to a variety of environmental and physiological conditions. He needs single tree information rather than broad averages for specific local cases. The use of individual tree responses to develop an average for a whole stand should provide an equally reliable base for future growth estimates.

There have been two basic approaches toward fulfilling the need for determining forest growth and yield under different silvicultural systems on differen sites. Both approaches employ simulation models of actual responses. One method is to use stand growth and yield data for different conditions and combine them into a stand model. The second method is to take specific data, usually individual tree growth, and develop stand responses.

As you can see from existing information, stand results are not reported on a similar basis, which makes the first method of comparison or combining difficult. Also, species combinations for mixed stands are most difficult to deal with.

Various stand growth and yield simulators have recently been developed for the northern forest types. Moser (1974) has developed a system of equations for forest stands of sugar maple in the Lake States. Solomon (1974) presented a simulation model for different silvicultural treatments of even-age northern hardwoods in New England.

The method of modeling that uses individual tree data allows significantly more flexibility; however, it requires more time to develop, and extensive field calibration. Many different individual tree models are available (Arney 1971; Beck 1974; Lin 1974; and Mitchell 1969). Simulation models have been developed for the northern forest types relying on different expressions of competition and growth. Hegyi (1974), for example, has developed a model for managing jack pine. Likewise Ek and Monserud (1974) have provided a model that deals with mixed species in even- and uneven-age stands.

Ongoing growth and yield research within the northern forest types is attempting to use individual-tree information together with stands to construct models.

Another urgent need is for the forester to measure products in more specific units. If we are to intensify our tree growth we need to know the responses of different tree components and how to measure this response. For example, volume, as measured by cords, is unsatisfactory for branches or leaves (Young 1973). Therefore we should bring the forestry world to a more common and precise basis, such as cubic meters, cunits, or weight. We need to be able to communicate as well as understand.

SUMMARY

For the land manager to manage his forests intensively, he needs growth and yield information for different species in mixed, even-age, and uneven-age stands on different sites with varying degrees of density and stocking. These stands need to have different combinations of these conditions both for managed and unmanaged stands.

Available growth and yield information deals with normal stands and some segments of managed stands. There is not only a need to develop growth responses for trees growing under different environmental conditions: there is also a need for collecting data and reporting results on a more common and conforming measurement basis. Therefore, the development of simulation growth models, as is being done, seems the most logical path to follow in an attempt to bridge existing gaps.

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THE STATUS OF TREE IMPROVEMENT PROGRAMS FOR NORTHERN TREE SPECIES

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Abstract

Forest tree improvement research and application in the Northeast is reviewed in the perspective of past development and future needs. Control over provenance selection can provide the best quality seed for today's reforestation programs. Future supplies of seed must come from seed orchards if forest land owners are to attain the maximum production per unit area as industrial reforestation efforts in the region increase.

When one considers the intensive culture of forests with any type of planting program, it is logical to include a tree improvement program to assure that you are planting seedlings of superior genetic quality. The very active and intensive tree improvement programs in the southeastern and western United States have focused worldwide attention on the tremendous gains that are possible through forest tree breeding (Zobel 1974). Foresters from the northern states visiting these areas are invariably impressed with the modern seed extraction facilities, expansive nurseries and greenhouse complexes, vast acreages of seed orchards, and the thousands of acres of fast growing plantations. In this paper, I would like to place in perspective for northern species the tree improvement activities to date and what I envision the prospects to be for the future. Most of my comments will be directed to the Northeastern states in general and Maine in particular.

As evidenced in the southeastern and western states, the development of tree improvement programs requires economic justification for their implementation. Forest industries and forest managers have responded to and accepted change only when they have found it economically advantageous. Several innovations in harvesting techniques in the Northeast such as tree-length logging and complete tree chipping have extended the fiber supply. These methods, however, became acceptable only when the lack of labor made it physically impossible to harvest a sufficient quantity of wood or the economics of wood production dictated a change. The same might be said of tree improvement in the Northeast: the acceptance of planting genetically improved seedlings by industrial and other foresters will result only when it becomes economically attractive or necessary, or because a potential shortage of raw materials requires a new approach to forest management.

PAST HISTORY OF TREE IMPROVEMENT IN THE NORTHEAST

The development of tree improvement in the Northeast is well documented in the "Proceedings of the Northeastern Tree Improvement Conferences", which have been held annually since 1953 (Garrett 1972). Notable among these accomplishments is that the first large-scale breeding project in the world devoted exclusively to the genetic improvement of forest trees was begun in 1924 by the Oxford Paper Company of Rumford, Maine in cooperation with the New York Botanical Garden (Schreiner 1975). The objective of this project was to produce rapid-growing poplar (Populus) hybrids for pulpwood reforestation. Today these hybrids have been planted extensively around the world. They have not, however, been planted to any large extent by the local industries for which they were developed.

Special mention should also be given to the early efforts made to breed American Chestnut (Castanea dentata (Marsh.) Borkh.) resistant to the chestnut blight fungus (Endothia parasitica) (Jaynes 1969). This effort was begun in 1929 by Dr. A. H. Graves of the Brooklyn Botanic Garden and has been continued to date by the Connecticut Agricultural Experiment Station.

With the exception of the two previously mentioned examples, most of the early tree improvement work in the Northeast was concerned with species introduction and provenance testing. Emphasis was placed on european and asiatic conifers adapted to plantation culture. These early tests quickly pointed out the significant contribution genetics makes to growth rate, seedling survival, form, wood properties, etc.

CURRENT RESEARCH PROGRAMS

Programs in tree improvement research are currently being carried out in all of the Northeastern and Lake States as well as the Canadian provinces. The work is being conducted by universities, federal governments, state agencies and private industries. The areas of investigation for purposes of discussion can be categorized as follows: (1) exotic species introduction and provenance testing; (2) individual tree selection and progeny testing; (3) hybridization; and (4) vegetative propagation.

Exotic species introduction and provenance testing. The northeastern region of the United States including the Lake States and southeastern Canada are very fortunate to have climates similar to several northern hemispheric regions of the world that contain valuable forest tree species. This condition permits us to successfully plant several of these species and in many instances obtain growth rates superior to our indigenous species. Today proper species selection and specific provenance recommendations can be made with a high degree of assurance for success. Besides the early provenance tests, several recent large-scale intensive provenance tests of indigenous species have been assembled and are currently being field tested in both the United States and Canada. For the most part, these recent tests are being conducted on species that show a large amount of genetic variation (e.g. jack pine (Pinus banksiana Lamb.)) or species that have gained in importance in recent years (e.g. black spruce (Picea mariana (Mill.) B.S.P.) and white birch (Betula papyrifera Marsh.)).

Both the earlier and more recent tests have shown dramatic differences for such traits as: (1) growth rate in white spruce (Picea glauca (Moench) Voss), eastern white pine (Pinus strobus L.), Norway spruce (Picea abies (L.) Karst) and Scotch pine (Pinus sylvestris L.); (2) form and foliage color in Scotch pine; (3) disease resistance in jack pine; and, (4) frost resistance in Douglas fir (Pseudotsuga menziesii (Mirb.) Franco) (Nienstaedt and Teich 1972, Wright 1970, Baldwin et al. 1973, Wright and Bull 1963, King and Nienstaedt 1965, Hattmer and Konig 1975). The general area where most information is still lacking is with hardwood species, however, this void is rapidly being filled as hardwoods are destined to become more important in this region.

Individual tree selection and progeny testing. The tree improvement programs in the southern and western states have for the most part been based on individual tree selection and progeny testing. The primary reason for this is that at the inception of the tree improvement programs in those regions in the 1950's, there already existed extensive planting programs and the immediate need was to obtain the maximum amount of genetic gain in the shortest possible time span. The approach taken was to establish clonal seed orchards from highly selected trees. This need, to obtain immediate genetic gain, did not exist to the same degree for most northern species as planting programs were comparatively small. Thus, individual tree selection was not given much emphasis. During the last fifteen years, however, this field of research has expanded rapidly and selection programs have been made or are currently in progress for many of the commercially important species. Population parameters and heritability estimates are rapidly being gathered for the commercially important traits such as growth rate, specific gravity, etc. (Morgenstern et al. 1975).

Hybridization. Inter-specific hybridization in the pines, spruces, poplars, and larches have produced several combinations that hold considerable promise for increased growth (Fowler and Yeatman 1973). Perhaps the hybrid in the Northeast that has received the most attention besides hybrid poplar is the *Larix decidua* x *leptolepis* combination. Trees from this cross have made astounding growth on well-drained sites throughout the region. Both seed and seedlings are available periodically from the state of New York.

Vegetative propagation. Methods of vegetative propagation by grafts and cuttings have been developed for the important northern species. Much research, however, should still be conducted on the grafting and rooting of spruce species. Especially critical is the propagation of trees that have been attacked by the spruce budworm (*Choristoneura fumiferana* (Clemens)). In recent years much progress has also been attained in the methods of cell and tissue culture as a means of vegetative propagation (Brown 1976).

ANALYSIS OF THE APPLICATION OF RESULTS

The ultimate objective of all tree improvement programs is to control seed quality. Ideally all seeds sown in nurseries or greenhouses should reflect some degree of genetic control. This objective has been attained by several organizations, however, it is still lacking in others. The practice of buying cones and seed on the open market still exists. The greatest degree of control has been attained in the Lake States, Canadian provinces and the state of New York. In these areas: (1) seed zones have been established to regulate the flow of seed across ecological zones; (2) seed production areas have been established for many species to ensure a continuing supply of seed from designated areas and environments; (3) seed orchards have been established. The 1974 Directory of Forest Tree Seed Orchards in the U. S. lists 434 acres of seed orchards for all species for the geographic region from Connecticut to Minnesota. This number is quite small when compared to the fact that Florida alone has 1606 acres of seed orchards.

FUTURE PROSPECTS

The amount of acreage planted each year in the northern region has steadily decreased since it reached its maximum in the early 1960's. These plantings for the most part were federally subsidized by the Federal Soil Bank Program and established on abandoned farm fields.

I believe the Northeast will see a dramatic expansion of applied tree improvement and planting programs in the near future. This development, especially in the state of Maine, will be spearheaded by forest industries. The need will be brought about by the growing demand for fiber and the realization by industry and state governments that cutover forest lands must be fully stocked with suitable species at a desirable spacing as soon after cutting as possible so that optimum growth can be attained. The need now for the region is one of "applied technology". A sufficient background of information from researchers in the United States, Canada and the Scandinavian countries on containerized growing, accelerated growth, site preparation and genetic principles exists to mount a truly active tree improvement program.

In Maine alone there are approximately 17.2 million acres of commercial forest land. Traditionally the State has been in the very favorable position of having an annual cut well below the growth. However, long-range forecasts by the U. S. Forest Service predict that by the year 2000 we shall have twice the demand for pulpwood than we now produce (Ferguson and Kingsley 1972). As implied earlier, improved utilization can augment and extend timber supplies, but the major long-term reliance must rest entirely on increased productivity of all available commercial forest land. This increased productivity can be attained by sound investment in the land and those trees growing on the land.

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STATUS OF HERBICIDE TECHNOLOGY FOR CONTROL OF TREE SPECIES AND TO REDUCE SHRUB AND GRASS COMPETITION

by Maxwell L. McCormack, Jr., Professor of Forestry, Department of Forestry, University of Vermont, Burlington, Vt.

Abstract

The values of herbicides as silvicultural tools are summarized. Treatments are discussed with reference to chemicals and methods of application as they pertain to control of grass and herbaceous weeds, understory vegetation, and overstory vegetation.

An herbicide is a chemical used to reduce or eliminate the detrimental effects of undesirable plants. The potentials for effective use of herbicides in the culture of northern forest types are much greater than current practices indicate. Herbicides are an effective, low cost, easy to apply means for reducing management costs and impact from forest pests while improving growth rates, wildlife habitat, watershed quality, and other objectives of forest management. Though herbicides play an important role in nursery practices, the concern of this report is the production of forest products. Competition from adjacent plants, as undesirable species or stems in an overstocked stand, is a major deterrent to growth and pest resistance of desirable trees. However, uses of herbicides go beyond removal of plant competition and can be grouped into several major categories.

1. Site preparation and preplant treatments
2. Control of species composition
3. Reduction of stocking levels
4. Direct reduction of competition from undesirable plants
5. Establishment of openings for such purposes as wildlife management and scenic vistas

6. Improving access through maintenance of roads and right-of-ways

7. Marking of treatment areas

8. Protection by removing host plant material

9. Protection through firebreak maintenance, and others as management needs require

Alternatives to herbicides such as mulching, cultivation, mowing, and other forms of mechanical treatment are more costly. Often they cause physical injury to desirable tree stems and their root systems. Increased erosion and pollution often result. Abrupt changes in forest environments and consequences of quantities of slash dropped directly to the forest floor from mechanical treatments, as opposed to gradual opening and crop tree conditioning accomplished through herbicide techniques, are factors worth careful consideration.

Herbicides offer many solutions to silvicultural problems. Consideration should be given to the original cause of the undesirable plant material such as harvesting methods, species preferences, residual cull trees, and pest impacts as well as management objectives based on ecological principles rather than a simple policy of eradication of the unwanted. Herbicide techniques appropriate for use today may be inappropriate for tomorrow. Continuous advances in application technology and development of new chemicals make new treatments available. Environmental conservation interests, legal restrictions, applicator licensing requirements, and possible reduced availability because of labeling regulations and costs can make established treatments unavailable. Any treatments used must comply with existing regulations and applicators should consult with their appropriate regional pesticide coordinators. Specific data are available from such references as the Herbicide Handbook of the Weed Science Society of America.

A detailed account of all materials and techniques is beyond the scope of this report. Periodically, practical summaries of basic practices have been prepared (Stamm, 1964; Lindmark, 1965; Shipman and Farrand, (no date); and others). Proceedings of the Northeastern Weed Control Conference are a source of information on recent developments and additional summary information from other regions is useful (Oregon State University, 1967; Gratkowski, 1975).

Because of the large number of possible treatments, the status of herbicide technology will be generally grouped according to some common field situations.

CONTROL OF GRASS AND HERBACEOUS WEEDS

Intensive cultural practices involved in the production of Christmas trees have provided much information and experience in control of herbaceous weeds (Ahrens, Flanagan, and McCormack, 1969). Paraquat (1, 1'-dimethyl-4, 4'-bipyridinium salts) has been useful for preplant preparation at rates of 1 to 2 pounds active ingredient per acre treated (lbs. ai/a). Rapid killing back of above ground plant material provides for easier planting and subsequent weed control. Health hazards associated with paraquat make special safety equipment essential and can be cause for using substitutes. Glyphosate (N-phosphonomethyl glycine) is a new material that shows great promise for killing weeds prior to planting. It is a postemergence, relatively non-selective, non-residual material which will control a large number of narrow and broadleaf perennial and annual weeds, trees, and brush. It has the additional advantage of exhibiting active translocation from vegetative plant parts to underground roots or rhizomes. It is best applied at early flowering to maturity.

Residual control of herbaceous weeds is best achieved with simazine (2-chloro-4, 6-bis(ethylamino)-s-triazine) applied as a spray of wettable powder in water. Simazine has good residual action and should be applied early in the spring for best results. Response from late season applications can be accelerated through the use of wetting agents which also help to keep spray equipment clean and functioning. Simazine works well with our native conifers with balsam fir (*Abies balsamea* (L.) Mill.) tolerating highest rates, followed by the pines (*Pinus* L. spp.) and then spruces (*Picea* A. Dietr. spp.).

Action of simazine can be accelerated and improved by combining its application with that of fertilizer. In turn, simazine also provides nutritional benefits by improving the nitrogen regime and the habitat for mycorrhizal fungi. This latter relationship has been observed with balsam fir, Fraser fir (*Abies fraseri* (Pursh.) Poir.), white spruce (*Picea glauca* (Moench) Voss) and species in other areas (Uhlig, 1966). Simazine treatments to balsam fir result in increased survival and improved plant tissue production. In some studies this herbicide alone has resulted in better growth than combinations of fertilizer plus simazine. Planted balsam firs with weed control, primarily with simazine, as the only cultural treatment have grown to heights exceeding seven feet in five growing seasons after planting (Unpublished data, University of Vermont). Wildlife management implications and browse problems result from apparent preferences by browsing white-tailed deer (*Odocoileus virgincanus borealis* Miller) for simazine-treated balsam fir which have been related to resultant increases in crude protein (Morgan and McCormack, 1973).

Atrazine (2-chloro-4-(ethylamino)-6-(isopropylamino-s-triazine) which is similar to simazine, but more soluble, is also effective and can be used in combination with simazine for faster action and reduced rates of application. Care must be taken not to allow atrazine to contact soft, new growth on conifers or some defoliation can result. Generally, rates of 2 to 10 lbs. ai/a are effective depending on site and operating conditions.

Though most experience with these triazine herbicides has been with conifers, increased survival and growth has been achieved in plantings of black walnut (*Juglans nigra* L.), red oak (*Quercus rubra* L.), white ash (*Fraxinus americana* L.), and yellow-poplar (*Liriodendron tulipifera* L.) (Erdmann, 1967). Recent field observations in Vermont indicate that sugar maple (*Acer saccharum* Marsh.) will seed in and grow well in maintained simazine bands.

CONTROL OF UNDERSTORY VEGETATION

Undesirable understory vegetation must be approached with special care to avoid injury to desirable overstory trees. This can be accomplished by careful application of herbicides with hydraulic sprayers or mist blowers in hardwood and softwood stands. Best approaches are with translocatable foliage applications. It is recommended that basal spraying be avoided since it requires larger volumes of chemical and oil carriers which are undesirable from the viewpoint of environmental and aesthetic concerns.

Best results are obtained with 2,4,5-T (2,4,5-trichlorophenoxyacetic acid). Other phenoxys are also used successfully as separate applications or in combinations. Silvex (2-(2,4,5-trichlorophenoxy) propionic acid) is effective as well as treatments including 2,4-D (2,4-dichlorophenoxyacetic acid). Glyphosate shows promise, but requires more study. Krenite (ammonium ethyl carbamoylphosphonate) may also have some application in the future, but must be applied late in the season. Initial responses to foliar sprays of Krenite simulate normal autumn loss of foliage which has some advantages where recently treated areas might be viewed by the public. Attempts at using amitrole (3-amino-1,2,4 triazole) can result in some root uptake which is potentially injurious to small overstory trees.

The "workhorse" of this category of treatments is 2,4,5-T which is effective in rates of 1 to 3 lbs. ai/a. Mist blowers give most efficient coverage using water as a carrier. Several adjuvants are now available to improve wetting, penetration, translocation, and weatherability. The disadvantages of oil in the carrier can now be avoided. To accomplish thorough kill, it is important to achieve good intake for translocation of the herbicide; quick burning of foliage which is dramatically impressive often precludes this desirable objective.

In addition to beneficial uses of adjuvants, other modifications in technique show promise. For example, difficult to control red maple (Acer rubrum L.) has exhibited increased susceptibility to 2,4,5-T when phosphorus applications are combined with treatment (Brady, 1970). Also, changes in timing of application are possible. Some brush species are susceptible to spring herbicide treatments while conifers are still resistant. Screening tests in the Pacific northwest with genera present in the northeast (Alnus, Rubus, Acer, and Corylus) have been encouraging (Stewart, 1974).

Heavy invasions of Rubus often occupy openings in northeastern forests. Present studies in northern Maine and Vermont indicate that herbicide treatments show hope of suppressing the undesirable vegetation to the benefit of spruce and fir. To date silvex looks good at rates of 2 to 3 lbs ai/a and shows good control of all strata of Rubus, even when there is a closed upper canopy of leaves. Good results have also been obtained with 2,4,5-T glyphosate. Krenite exhibits potential, but will require more study. In cases where residual trees or larger plants are present it is important to take measures so they do not interfere with reaching target plants with herbicide applications

CONTROL OF OVERSTORY VEGETATION

Treatment of overstory plants, or stands of brush species where no trees are present, can be accomplished through foliar applications. Aerial applications can be very efficient. Spraying of 2,4,5-T controls hardwood growth sufficiently to allow establishment of conifers. Isolated trees which are larger than the target canopy can result in shielding so that separate preparation or followup treatments might be desirable. In cases where fresh stumps and girdled trees result in quantities of sprouts that are not desired for wildlife management purposes, herbicide treatments can be utilized to reduce impact from sprouting. Treatment of fresh cut stumps very soon after cutting is desirable. These applications are a good example of where colored dyes are a definite aid in efficient execution of treatment.

Aerial sprays using several phenoxys in Vermont have shown that all treatments including 2,4,5-T gave some level of control (Newton and Smith, 1971). Application of low rates of 2,4,5-T from fixed wing aircraft on relatively small areas, 17 to 54 acres, has been effective in reducing hardwood competition in softwood stands (Butler, Hudson, and Flanagan, 1963).

Where broadleaved brush poses a threat to conifers another material which has been effective is picloram (4-amino-3,5,6-trichloropicolinic acid). When combined with 2,4-D or 2,4,5-T in foliar applications, picloram provided better brush control than either of the phenoxys alone (Perala, 1974).

Hard to kill species and individual large stems may need special attention where foliar sprays are used. Where combination treatments or removal of selected large stems are the basis of timber stand improvement operations, injector or frill-plus-chemical applications can be very effective. In effect, a frill plus herbicide is a continuous series of injections around the circumference of a stem. Injection by long-handled tree injector at the root collar or hypo-hatchet at a convenient working height has the advantages of being neat and efficient, and placing the chemical in an individual selected stem as a metered dose. Present techniques involve use of undiluted herbicide in rates of 0.5 to 1.5 ml per injection with spacing of injections regulating dosage. The phenoxys are used. Their effectiveness is increased, especially on red maple, by adding picloram. Very good results are obtained with the organic arsenicals. Depending on season of treatment, summer months appear to give best results, cacodylic acid works best to control beech (*Fagus grandifolia* Ehrh.). Monosodium methane arsenate provides control of red maple, sugar maple, striped maple (*Acer pensylvanicum* L.), white birch (*Betula papyrifera* Marsh.), aspen (*Populus* L. spp.), hophornbeam (*Ostrya virginiana* (Mill.) K. Koch), white ash, and conifers which is equal to, or better than, cacodylic acid (Newton and Smith, 1971). Materials and dosages vary with species and season. Several existing reports provide practical guidelines (Little and Fenton, 1964; Filip, 1965; Peevy, 1972; and others).

SUMMARY

Numerous opportunities exist to use herbicide treatments for intensive culture of northern forest types. Each situation must be evaluated for its specific requirements so an ecologically sound treatment can be directed at realistic, undesirable target vegetation while exposure of non-target organisms is minimized. All must be done within legal restrictions. It should be remembered that complete kill of undesirables is often not necessary and a significant positive response of the desirable trees is the objective and proof of beneficial treatment.

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COMPATABILITY OF INTENSIVE TIMBER CULTURE WITH RECREATION, WATER AND WILDLIFE MANAGEMENT

by Samuel P. Shaw, USDA Forest Service, Northeastern Area, State and Private Forestry, Upper Darby, Pa.

Abstract

Two principles of ecology can be applied to make management for recreation, water, and wildlife habitat compatible with timber management. They are diversity within plant communities (i.e. timber types) and interspersion of these diverse communities in place and time. Intensive cultural operations can be the tool to create the right mixture of diversity and interspersion to serve the priority needs of the landowner. This requires imaginative planning and the recognition of key-value areas. Areas where recreation, water, and wildlife assume the key position are relatively small compared with timber. Usually, timber operations can be carried out on at least eighty percent of the land with only slight modification to accomodate other resource values. Forest management based on such a multiple-resource approach overcomes small losses in timber income with large gains in public acceptance.

Reliable information links timber with recreation, timber with water, and timber with wildlife, but I can find no investigation that considers all of these at one time. My assignment is to lay the groundwork for pulling these four values together into one management package for the forest landowner. Recreation, water, and wildlife have different meanings to different people, so I will begin by defining what they mean in this paper.

DEFINITIONS

Recreation

Forest recreationists can be separated into three broad groups (Fletcher 1975). At one extreme are the relatively few but vocal solitude seekers who require large undisturbed, inaccessible back-country. At the other extreme is a larger group of socializers who derive their pleasure from resorts, fancy campgrounds, and other places where man-made facilities dominate the landscape. Although it is important to satisfy the needs of both these groups, I am assuming that public agencies will provide for the solitude seekers, and private capital will take care of the socializers. Seldom does either group see timber cultural operations in action.

This paper is concerned only with that vast in-betwee group of *moderates* who may enjoy some solitude and socializing in small doses but derive their greatest satisfactio from a casual type of recreation in a more natural forest environment. These are dispersed recreationists who use t woods for such activities as pleasure driving, hiking, bicycling, picnicking, hunting, fishing, birding, nature study, photographing, horse back riding, and casual campin

Most of these activities require some access for vehicles, along with small woods roads and trails for walkin into remote areas of the forest. The quality of the exper ence is based mostly on visual impressions of the forest setting. Eighty-seven percent of man's perception is base on sight (USDA, 1973), and aesthetically pleasing landscap relate directly to high quality experiences. In other wor recreation in this paper means forest aesthetics.

Water

Our main concern is the effect of manipulating forest vegetation on the quantity and quality of water appearing in the forest in the form of wetlands (marshes, shallow-water areas, swamps and bogs), springs and seeps, streams, lakes, and reservoirs. Wetlands attract recreationists an scientists because of their special ecological values, and they provide habitats for unique forms of plant and animal life rarely found elsewhere in the forest.

Many springs and seeps have these same values, and th supply drinking water for both humans and wildlife. The fishery values of streams, lakes, and reservoirs attract anglers. Treatment of riparian vegetation is especially critical, but any cultural operations which affect underground and surface flows to these water areas are also important.

Wildlife

Wildlife includes primarily birds, fish, and mammals, although lesser forms are considered if they have special scientific or public-interest value. Game and nongame species are considered equally, unless the landowner indicates otherwise. The goal is to insure healthy population of as many species as possible. The system to achieve thi is referred to as "management for species richness" (Evans 1974). It allows special attention to the habitats of unusual interest such as eagle nesting sites, locally unique plants and animals, songbird habitat along nature trails, and deer yards.

CONCEPTS

Ecologists and wildlife managers use two guiding principles or concepts: diversity and interspersion. I believe both of these can be used, in different combinations, to set priorities and procedures for coordinating recreation, water, and wildlife management into a single forest management plan. Cultural operations carried out by timber managers should be a major tool for achieving coordinated action. There will be a few exceptions where relatively small special-interest or sensitive areas need prescriptions by a biologist, hydrologist, landscape architect, or some other nontimber specialist to give full recognition to the various resources.

Diversity

Diversity is the amount of variation that exists in plant and animal communities. It is synonymous with variety. Some examples are:

(a) Successional stages within the same timber type, such as bare ground, early invaders (herbs and shrubs) and stands dominating by seedlings, saplings, poles, and sawtimber; i.e. certain species prefer young stands while others may be found only in old growth.

(b) Border between two broad timber types such as northern hardwoods and spruce-fir.

(c) Nontimber areas like grassy fields, bogs, log landings, water areas, fire lanes, and facility right-of-ways.

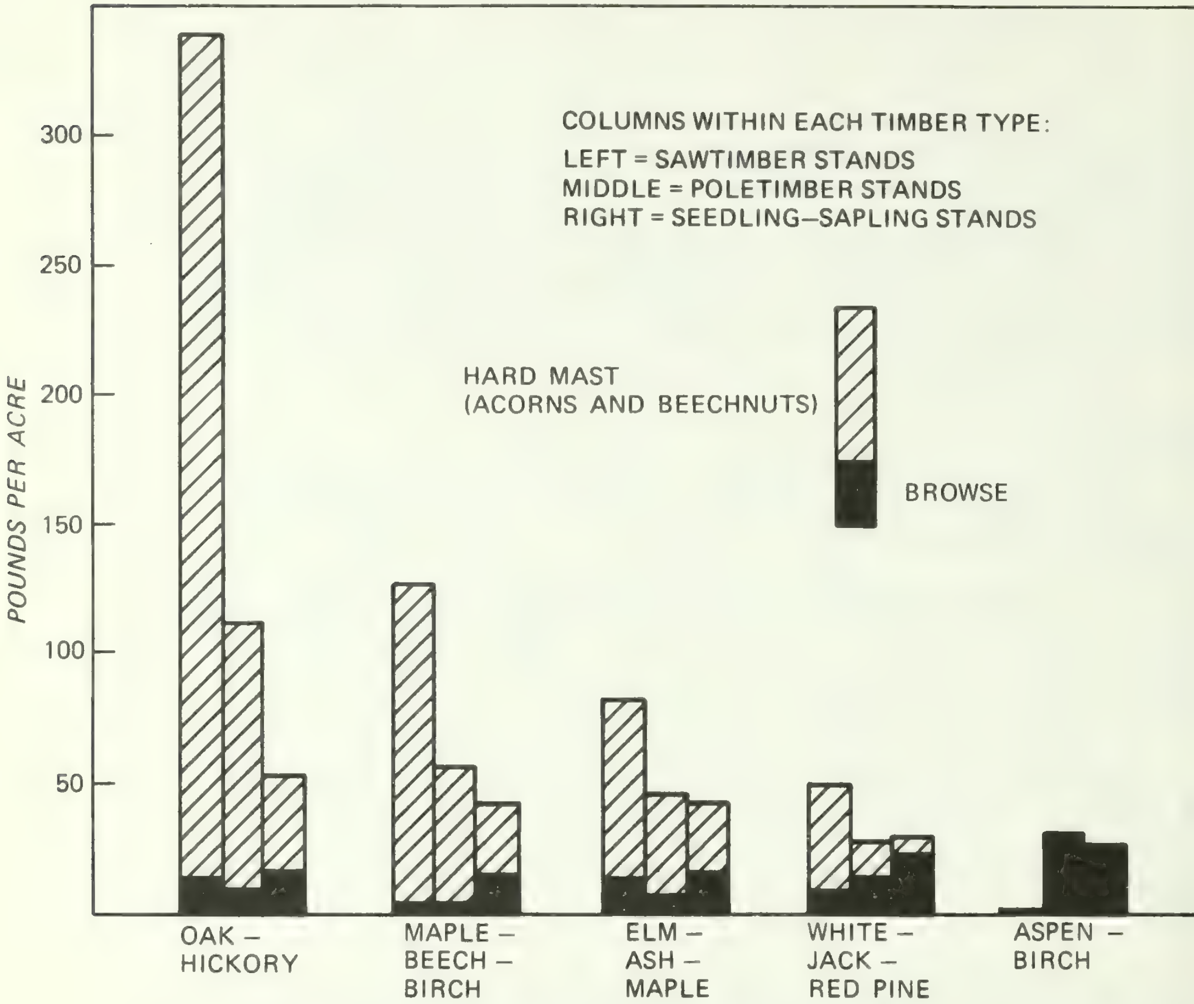
(d) Isolated stands of trees which are not typical of the surrounding timber type such as a beech-birch-maple stand within a spruce-fir type, or an aspen-birch stand in a northern hardwood type.

(e) Large conifer plantations broken up by unplanted strips.

Diversity occurs where different plant communities or successional stages within them come together. Wildlifers call this edge. The forest edge habitat usually contains many of the plant and animal species of each of the adjoining communities plus those characteristic of (and sometimes restricted to) the edge habitat itself. For example, both the diversity of bird species and the density of some are greater in the edge than in either community flanking it (Odum, 1959).

An example of the need for diversity is shown in Figure 1. Information comes from Barnes (1976) who used

Figure 1. Relative importance of winter deer foods by timber type and stand size class in the seven southern counties of New Hampshire.



Forest Service survey plots to evaluate the amount of woody browse and hard mast (acorns and beechnuts) available to deer during the winter. He gives results according to three age classes in each of five forest types found in the seven southern counties of New Hampshire. Mast and browse are staple winter deer foods.

To have both mast and browse requires a combination of timber types and age classes. For instance, a sawtimber stand in the maple-beech-birch type is a relative high producer of mast but a very low producer of browse. A pole or seedling-sapling stand of aspen-birch, on the other hand, is a very high producer of browse but provides no mast at all. This means that if a young stand of aspen-birch adjoins a maple-beech-birch sawtimber stand, there would be ample supplies of both browse and mast. Diversity, in this case, results in improved winter deer range.

Another example of how diversity works in favor of wildlife comes from an Ontario study of breeding birds in relation to three broad timber types (MacDonald 1965).

Timber Type	Bird Species Represented	Pairs per 10 Acres
Northern Hardwood with Mixed Pine	18	36
Semi-Open Pine	6	15
Pine Plantations	1	1

Interspersion

Interspersion is the degree to which different plant communities or successional stages -- in other words, diverse habitats -- are randomly mixed within the mobility range of wildlife and recreationists, or within a watershed.

We can use clearcutting on a 200-acre woodlot to illustrate. If there were one 25-acre clearcut in the middle of the lot, there would be localized diversity but poor interspersion because this diverse condition is not repeated elsewhere. On the other hand, if there were five 5-acre clearcuts scattered over the lot, one in each 40-acre block, there would be good interspersion.

We know that diversity combined with interspersion is extremely important in managing wildlife habitat because they combine to create a good assortment of places, called niches, where various species can find suitable habitat to feed, hide, rest, sleep, play, and breed within their home range. Diversity and interspersion are also important considerations in forest aesthetics and watershed management.

Forest Aesthetics

Those in the environmental planning profession use three basic concepts -- variety, harmony, and contrast -- and the three are interrelated (USDA 1965). On the subject of variety, which is the same as diversity, this source states:

> "Variety produces that changing quality of the landscape that captures and holds one's interest. A continuing diversity or change leads one to anticipate something different and delightful around the next bend in the trail or beyond the next ridge. In planning for variety one should ask, "How will people use or view this?" Is it both functional and interesting, or is it too much like that which has gone before? Variety is truly the spice of life, but it must not be allowed to run wild. It must be balanced with just the right amount of repetition to prevent chaos and confusion."

There is no question that timber cultural operations can be planned to create that "right amount of repetition."

Water Management

Normally, water yield increases directly with the amount of basal area removed. Consequently, even-aged management has a greater effect on the magnitude of water yield than uneven-aged management (Curtis and Ripley 1975). Light thinnings rarely affect streamflow, but clearcutting on a northeast deciduous forest can increase annual water yield the first year by 4 to 12 inches. These increases decline each year after cutting, and in 10 to 15 years water yields return to pretreatment levels (Lull and Reinhart 1967)

It follows that to maintain a high sustained water yield, new areas must be cut periodically as earlier cuts mature. These cuts create diversity and interspersion. They can be planned in space and time to enhance aesthetics and wildlife habitat.

EXAMPLES

Now we will look at some examples of how aesthetics, water, and wildlife can be coordinated for their mutual advantage as cultural and other operations are carried out as a part of timber management work. Selected practices are shown in Table 1. Several of the recreation (aesthetics) examples are taken from Noyes (1968). Some modifications benefit all three resources simultaneously. These are list-

Table 1. Examples of how recreation, water, and wildlife values can be enhanced by modification of certain timber management operations.

		Recreation (aesthetics)	Water (yield)	Wildlife (habitat)
1.	Plantation Establishment	Create variety by planting evergreens in pure deciduous stands, and vice versa.	Favor deciduous over evergreen trees. Thin plantations frequently to break up canopy.	Leave unplanted travel lanes every 600 feet. Thin frequently to favor ground vegetation.
2.	Weeding	Favor trees with aesthetically pleasing crown, bark, foliage, and flower colors. Leave trees not commonplace to location.	No measurable effects	Favor trees and shrubs with high food or cover values: i.e. mountain ash, crab apple, and small hemlocks.
3.	Pruning	Concentrate work along trails and wood roads for easier access and greater safety. Maintain some naturalness by not overpruning (i.e. 100 crop trees per acre).	Slight increase in water reaching forest floor.	Leave live unpruned patches along roads and trails used for birding. Pile branches for wildlife cover.
4.	Improvement Cutting	Create vistas or views of unique features by heavy cutting. Avoid deadening trees in places frequently seen by people.	Cut heavier than usual and frequently as possible. Favor retention of deciduous over evergreen trees.	Leave productive mast-producing and den trees. Release patches of small evergreens for cover.

Table 1. (cont.)

		Recreation (aesthetics)	Water (yield)	Wildlife (habitat)
5.	Cutting for Uneven Aged Management	Use especially along roads, trails, water bodies, and recreation areas. Retain trees and shrubs of high aesthetic appeal. Log in dormant season to reduce residue mass. Lop tops.	Use single tree selection and cut lightly in buffer strips to prevent silting.	Favor group selection over single tree to put more "brush in the sun". Favor retention of best mast and den trees.
6.	Cutting for Even Aged Management	Create undulating edges when regenerating, with small tongues of standing trees extending into cut area. Blend cuts into terrain. Scatter debris and keep it low.	Do not cut on steep slopes, erosive soils, or wet areas. Supervise operation closely to prevent damage to stream channels and other sensitive areas.	Shape large regeneration areas so short axis stays within average of 500 to 800 feet. Scatter cuts over management unit. Four 20-acre cuts better than one 80-acre.
7.	Log Roads	Plan location for use after sale by recreationists for vehicle or foot access to high-interest spots. Leave roadside trees and shrubs with high aesthetic appeal.	Avoid locating roads in wet or poorly drained areas. Seed steep slopes with grass or clover to prevent erosion. If stream must be crossed, build bridge or use culverts.	"Daylight" some stretches to create early - succession vegetation along edges. Seed roadbed with clover. Gate certain remote areas for hunters, birders, or others who want a back-country exper-

ed under the resource believed to be benefitted most. For example, daylighting and seeding log roads improves aesthetics, water yield, and wildlife habitat, but it is listed under wildlife as the most enhanced resource.

All the modifications shown in Table 1 result in increased diversity of one kind or another. Good interspersion results when these practices are scattered over the management unit. Modification of timber operations is the most practical way to achieve diversity and interspersion on the ground.

APPLICATION

The management program for the Quabbin Reservoir lands in Central Massachusetts illustrates how many of the principles, practices, and modifications discussed here can be applied. Highlights of this program are given in an article titled CURRENT MANAGEMENT PRACTICES ON METROPOLITAN BOSTON'S MUNICIPAL WATERSHEDS, by Bruce A. Spenser. It appears in Municipal Watershed Management Symposium Proceedings, 1975, available from the Northeastern Forest Experiment Station at Upper Darby, Pa. It is a good reference. Here are a few highlights:

Management zones are delineated, and specific management policy developed for each zone. Six zones are recognized, occupying the following percentages of the 75,000-acre management area.

Area Use	Percent
1. Watershed Management	83.0
2. Aesthetics	6.0
3. Protection	6.0
4. Administration	0.5
5. Wildlife	3.5
6. Recreation	1.0

Each zone requires specific silvicultural practices. The silvicultural goals are to maintain and improve the health and quality of the forest; salvage defective, mature and dead trees; and prepare sites for the regeneration of native species. Spenser states:

> "In the past 10 years, watershed-management operations treated 10,000 acres of forest, and should have yielded an additional 3.3 billion gallons of water, valued at $200,000, plus 33 million

> board feet of stumpage valued at $658,000. This decade (1970-1980) we will treat 12,000 acres and produce similar yields but of greater value. This increased water yield seems like a small contribution, but it is more economical and of higher quality than other additional sources of water."

Here is a Municipal District Commission in business primarily to produce quantity and quality water for human consumption. Significantly it accomplishes its goal with a very active timber improvement and harvesting program. At the same time it is responsive to aesthetic, recreation, and wildlife priorities -- good evidence of multi-resource compatibility. Application of the principles of diversity and interspersion, I believe, can help create and maintain this compatibility.

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PLANNING PITFALLS

by James H. Freeman, Director, Programming and Land Use Planning, USDA Forest Service, Eastern Region, Milwaukee, Wisconsin, Symposium of Intensive Culture of Hardwoods, University of Maine, Orono, Maine, July 22, 1976.

The subject this morning is planning and the problems peculiar to planning for management on public lands. As I am sure you know, we could devote entire seminars to problems encountered in planning. However, within the scope of the program today, we have the opportunity to touch briefly on some of the more important highlights of planning with the focus on major factors that influence the usefulness and continued viability of our plans.

When we consider long and short range planning involving forest resources, it is well to remember the hierarchy of plans that has evolved over the years. With the development of the assessment and subsequent program required by the Resources Planning Act, the Forest Service has seen the top planning level of our hierarchy of resource land management plans come of age. The hierarchy of plans can be illustrated in this fashion with the R.P.A. program being represented at the national level. (Table a)

1. Note the mix of management plans and budget, and programming activities.
2. The downward flow of direction and,
3. The provision for feedback.

Why is this hierarchy important to us?

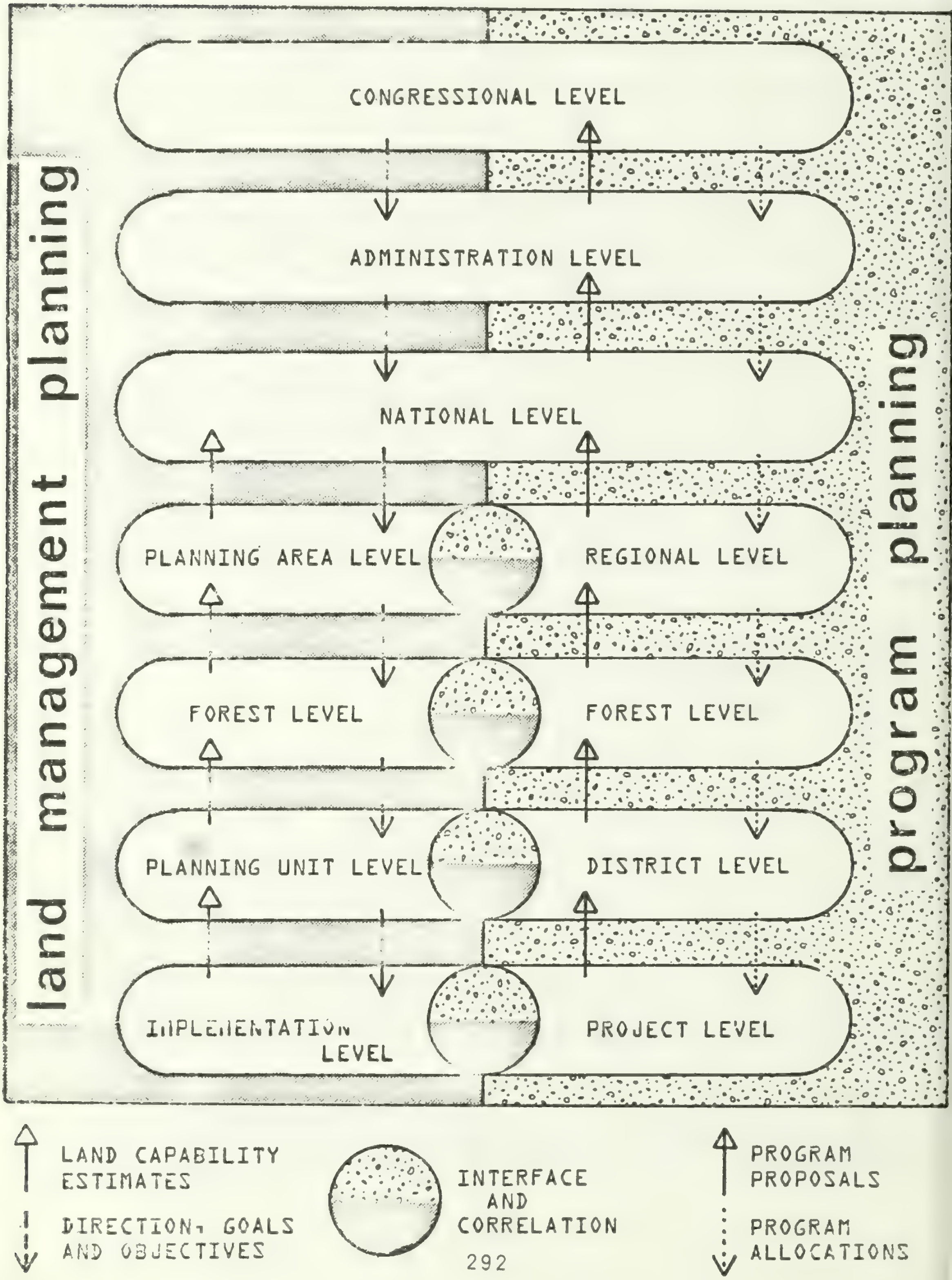
For one thing, it helps to inject a sense of structure and organization into the overall planning process. That structure, keyed as it is to organization level reinforces our ability to build a set of dependent plans that are responsive to both direction and objectives set from higher authority, and to knowledge of local concerns and land capabilities developed at ground level.

It also serves another very important purpose. It visually illustrates to us the intended interdependency of the land management planning, the programming of activities, and the actual funding of projects.

So, now we can begin to relate to a basic question that I believe must be answered in the minds of the people engaged in a planning job. To be at all successful, a planner or planning

TABLE a

FOREST SERVICE PLANNING RELATIONSHIPS



team must understand why a planning activity is necessary or desirable. This seems basic but it is surprising how often people can lose sight of their basic purpose as they become emeshed in the process of developing a plan.

So, why do we plan? In the National Forest System, we plan in order to achieve selected (directed) objectives in the most effective, efficient manner available. A fairly simple statement. However, in practice the question becomes more complex; and we replace the original question with several that are more difficult to answer.

What are the objective(s) we wish to achieve? How will we measure effectiveness? What yardstick will we use to measure efficiency" How will we know when we have satisfied our objectives? What time factors are involved?

You may feel these are all rather basic questions with obvious and mutally understood answers. However, failure to deliberately address each of these areas and to reach mutual understanding on the answers between members of a planning team is a common pitfall in many troublesome planning efforts.

When it comes to objectives, it is necessary to distinguish between what I call "planning" objectives and the final output related results or management objectives that are the end product of the plan directed actions. For example, planning objectives are fulfilled for the most part through the process of developing the plan. They may include such things as, "provide an opportunity for local and county officials to participate in the planning process, or to involve specialists in the fields of anthropology, forest economics, and landscape architecture in the analysis of alternative courses of action."

On the other hand, management objectives relate to the primary results desired and are usually achieved as a result of carrying out actions prescribed by the plan. Examples of such objectives include: provide for an annual timber harvest level between X cunits and Y cunits by 1990, provide dispersed recreation opportunities for 900-1100 PAOT by 1985, maintain wildlife habitat diversity at current levels and so on. These objectives, quantified and dated, become planning guides and later are the yardsticks against which the ultimate success of planning and execution is measured.

So far so good, except that about now someone usually says, "just a minute." "You haven't described any planning activities yet and already you have established your output targets." "You've come to the bottom line before you start." "Where did those management objectives come from?" If you have already decided what you are going to do, there really is no use playing all these planning games!"

There is a parable that is aprepo here that says, "Any road is a good road if you don't care where you're going," and by the same token, any plan is fine if you don't care what the results are. Without objectives. there is very little to use to determine whether a plan and its alternatives is even heading in the right direction. So I look for those management objectives and I find them as assigned targets contained in plans prepared at a superior level. Failing that, as is occasionally the case, objectives must be developed from an analysis of such things as: historical use patterns, predictions of future demands, timber survey reports, and population and economic growth predictions.

Objectives developed from such analysis must always be agreed to by the line officers responsible for making final decisions and approving the plan before proceeding.

There is a reward for this effort, for now that objectives are established and agreed to, the planning serves several purposes among which are to: test the capabilities of the area you are considering to provide the desired mix of output benefits, and to develop a number of alternative strategies for delivering the desired results.

A common problem area is a failure to do an adequate job of preplanning. An important product of preplanning is a PERT chart or general bluepoint for carrying out the planning process. A number of different display charts can be developed, but it is important to build these planning progress and schedule charts on a large enough scale to put on the wall and mark up on a daily or weekly basis. That way, important dates are least likely to be missed and jobs will generally proceed in the desired sequence.

During this preplanning phase, the individual who will ultimately be responsible for making the decisions has several critical duties.

One of these duties is to determine, to the extent possible, the major factors that will influence or have a bearing on the decisions that are anticipated. He may identify aesthetics, benefit/cost, soil movement, or other factors that his experience has lead him to regard as critical to decisionmaking in his area. This identification of decision influencing factors is by no means final at this stage, but it will help him identify the makeup of skills needed on the initial planning team. It is also useful in identifying the data needed during planning. This helps to offset a tendancy of some planning teams to get mired down in purposeless inventory and data collection.

Usually, the preplanning phase also will include an intensive training session for all members of the planning team. This training serves an essential function in addition to providing information on the expected planning process. That essential is the first step in the team-building process, which molds the individuals assigned to the planning job into a fully functioning group.

In the "preplanning phase" it is also time to begin the public involvement connected with the planning process. This in itself is a broad enough subject for a separate symposium so I'm going to simply say that the public involvement actions developed for any particular planning activity must be carefully designed to elicit full participation from the publics involved and must avoid meaningless meetings or requests for inputs for which there is no planned use. The key is early involvement in the process coupled with realistic use of the opinions and comments received. There is no use asking for comments or opinions on matters that cannot be adjusted as a result of the public comment and these items are often well identified as basic assumption or management direction.

Data collection seems to be a common stumbling block for many planning teams. The tendancy of many planners has been to try to collect much more information than is needed or really used in the decisions.

In some instances, of course, the collection of data is aimed at covering every conceivable, even remotely related, question. All this data is nice to have and may even be useful at some future time. However, quite often extra data collected on the basis that it may be useful sometime only confuses the issues when it comes to making decisions for the short time. I'm not advocating a careless disregard for the full range and variety of resources and factors that bear on any resource decision. I am saying there is a great need to make deliberate decisions early in and during the planning process, on what data is really needed to make the alternative selections, and on how that data will be used. Not only can this save time and prevent confusion, but there are some real cost factors involved in collecting, storing, and maintaining data.

A common rebuttal to deliberate limitations on data collection is to refer to possible challenges that may be forthcoming from some of the publics. Here our public involvement can serve as a very useful and sensitive sounding board. Continually during the process, the sensitivities and concerns of a wide variety of interests can be sifted and weighed to help determine the final decision criteria and the data needed for support. We have a number of tools to help us do this, and Here I refer you to the work of Dr. John Mendee and Roger Clark of the Pacific Northwest Forest and Range Experiment Station, and George Stankey from the Intermountain Station in developing the CODINVOLVE system for analyzing public comments. Their system isn't complicated but it is certainly useful in helping to organize and keep track of comments from all kinds of sources.

It must be understood that I am not suggesting that we can respond effectively to all challenges and questions through intensive public involvement efforts. What we can and do accomplish is to develop heightened sensitivities to peoples' concerns and values as they related to specific issues. This heightened sensitivity may help make our final action as responsive as possible to peoples' current needs as we can make them. And that's what we in both the public and private sector are working for.

The analysis of the data leading to decisions can employ many techniques ranging from computer assisted techniques to simple graphic comparisons. A key is to keep it simple and with a highly visable or traceable thread of logic.

Although the need to keep the analysis as uncomplicated as possible to provide for maximum understandability is great, there are several items that commonly need improvement.

One is economic considerations. It is imperative that we indicate, in our planning and analysis, the benefit/cost ratio we anticipate from our proposals. We must be able to identify the long term return on the investment we are recommending, and we should also be able to compare alternative courses of action in terms of long range returns and costs.

Another item for analysis that is often a problem is the determination of the effect of proposed or considered actions on archaeologic, cultural or historic features. Here the problem often lies with whether or not the issue has even been addressed. If no historic features are effected by any of our proposals, we must so indicate in our environmental analysis reports or statements and documenting evidence must be cited. Failure to address this issue has resulted in unnecessary delay and frustration. The key to dealing with the cultural, historic, or archaeologic resource is to address the issue squarely. Conduct whatever level of field reconassiance or survey is needed. Verify the presence or absence of cultural resources. Then deal positively with the subject according to Federal law and requlation.

The final point I would share with you today has to do with the need to provide easily traceable and visable evidence of the rationale used in making decisions. Many people, both from within the Forest Service and from other walks of life, are interested in decisions of public officials. Often all that is sought is to be able to easily trace through an open and understandable train of logic to a decision point. This doesn't guarantee agreement, but it may help build trust in the process followed. This may, in turn, lighten the case load of requests for administrative review and build credibility in our decisionmaking.

In covering this potpourri of problem points in public land management planning, I have not attempted to prescribe a cure all for all public planning efforts. Hopefully, some additionaly attention to some of the points I have touched on briefly will help smooth some of the wrinkles out of your planning efforts.

PLANNING FOR & IMPLEMENTING INTENSIVE CULTURAL
LONG & SHORT RANGE PLANNING

by Lester W. Hazelton, Director-Timberlands, Planning & Development, Great Northern Paper, Millinocket, Maine.

Abstract

Great Northern Paper, a major industrial forest owner in Maine (2,000,000 acres), began a program for more intensive silviculture in 1972. The first step has been a major woodlands reorganization into five geographical districts with forest management and procurement responsibilities delegated to these districts. This has been accompanied by a re-inventory of timberlands and development of a new computer-processed resource and information system (WIPS). Current and future major emphasis will be placed on improved administrative procedures for the very close coordination of wood procurement, logging and forest management functions to insure the realization of the maximum growth and quality potential of Great Northern's timberlands.

Introduction-background

Great Northern Paper, a division of Great Northern Nekoosa Corporation, is a major forest products manufacturer and forest owner in Maine with approximately 2,200,000 acres of total ownership. Initial purchases were for approximately 350,000 acres in 1900 with subsequent purchases taking place through to the early 1950's. Since that time, land sales, exchanges, and State park establishments have reduced total ownership, but Great Northern still retains nearly 2,000,000 acres of forestland. Our principal use and demand on this forest has been for the spruce (*Picea* (L.)) and fir (*Abies* (L.)) timber found in its softwood types.

The initial working or forest management plan for Great Northern's timberlands was developed by the U. S. Forest Service's forerunner, the old U. S. Bureau of Forestry, in 1904. It is interesting to note that the Bureau of Forestry's (Mr. M. C. Hodge, Jr.[1]) initial recommendation for operating these timberlands (365,000 acres) included minimum diameter limits on spruce of 12", on fir of 8", a projected cutting cycle of 53 years, and a cut regulation of 6,338 acres annually, with annual harvest volumes of 13,437,000 fbm. Although Great Northern has revised its forest management plans periodically over the past 70 years the initial thinking and silvicultural concepts which went into this original plan are still alive, still valid, and still form the basis for the recommendations made today by our present staff of foresters.

Great Northern's most recent plan revisions and developments for more intensive silviculture began in 1972 with a basic reorganization of the woodlands department into five geographical districts. This change was made concurrent with a major re-inventory of our total timberlands and the decision to develop an improved resource information system.

Our present and future emphasis for improved forest management will be on the actual administration of the forest and improved harvest operations to insure that Great Northern achieves the full potential in growth and economic returns from its timberlands. Thus the following brief case study of a planning effort by one large corporate owner will consider - I The Organization, - II The Information System and - III The Administration for that Forest Resource.

I ORGANIZATION

In 1972 Great Northern's demand for total softwood reached nearly 1,000,000 cords annually. This total demand on the forest resource had been carefully assessed during the 1960's and the supply was considered adequate to support it. However, in projecting for long range future supply on a state/national basis, including recent regional expansions in wood consumption, Great Northern made a considered decision to improve its own posture in relationship to the total forest resource. The first step was a basic reorganization of its Woodlands Department and in the functioning of its procurement-forest management responsibilities. A considered objective was to delegate and incorporate forest management responsibility more closely to the forest, to the stump itself, and to the people directly in charge of forest harvest and management operations.

Great Northern's total wood draw area includes nearly 40% of the State's total forest area, (6,000,000 acres) and a million acres or so of forest land in New Brunswick and Quebec. This area, influenced considerably by Great Northern's own land ownership pattern, was divided into five principal procurement-management districts. These districts range in size from 1,000,000 acres to 2,000,000 acres with GNP forest ownership in the districts ranging from a minimum of 100,000 ± acres in our Penobscot District to over 1,000,000 acres in our West Branch District.

The districts themselves for forest management purposes will be further divided into management units, consisting of several townships, with each township divided into individual planning units. The planning unit itself is a refinement of the old standard forest compartment and is designed to be the basis for all information and forest planning.

The major personnel and responsibility changes in our new district system have been the increase in forestry staff within each district and the direct delegation of nearly all forest management activity and responsibility to the district superintendent.

Previous to 1972, Great Northern had a loosely structured Purchased Wood and Operated Wood procurement districting with total forest land management responsibility centered at the Woodlands Department headquarters (Division of Forest Engineering).

For a large industrial forest owner and consumer of the forest, who is as concerned with the economics of the harvest as with forest growth, this close integration of responsibility for the success of the total system is critical. We have been pleased with many features since inaugurating this new districting (more innovative thinking by field forestry personnel) but we still have much to do to fulfill original organization objectives.

II RESOURCES INFORMATION SYSTEM

As Great Northern considered its position in regard to silvicultural decisions, softwood supply and also expansion into other products, it became apparent that an improved resource information system was a necessity. Great Northern's last complete inventory of its forest lands had been performed in 1953. Since that time inventories had been kept current through systematic measurements of growth plots and, of course, harvest deletions. The existing inventory records for softwoods were considered accurate, and in fact have been so confirmed by the recent re-inventory conducted by the James W. Sewall Company (completed in 1976). However the hardwood volumes and other miscellaneous species had not been as well addressed. These considerations, plus the need to develop a total computer-processed forest data base on which to develop supply-demand projections, silvicultural and land-use programs, prompted a management decision for a complete and new inventory of the forest. This re-inventory was finished last month.

The new forest inventory will become part of, will be controlled by, will be manipulated, and drawn upon by a newly installed forest resource information system (GNP-WIPS - Woodlands Information & Planning System[2]). This system, of course, is computer processed. The principal design work and installation of this new system has been the prime responsibility of Mr. L. O. House, a recent staff addition to Great Northern's Woodlands

Department.

Briefly summarized, the WIPS system will furnish us with the following:

1. Effective and rapidly developed long and short range harvest options for basic planning units, management blocks, districts and for the total woodlands' operation.

2. Effective and rapid update of information for the total forest resource and the total land area (Land Use Planning).

3. Rapid evaluation of varied silvicultural systems, their effect on the total forest and on district forestry management.

The WIPS system as presently structured consists of the following subsystems:

- A data base - the informational heart of the system.

- A master file - for each basic planning unit (2,000 to 4,000 acres), an informational filing system on microfiche for district and staff day-to-day use.

- Pre-operation evaluation - stand and operational cruising for product volumes and silvicultural information.

- Inventory updating - growth and inventory plots randomly located.

- Growth and yield simulation - prediction of future stands.

- Capital investment evaluation

- Short range planning

- Long range planning

Although the development of this total information system is far from complete we have already begun to reap some of the benefits from it. Cruises this past spring for example have been rapidly computed (within 1 or 2 wks. after completion) with a wealth of necessary stand information available for district foresters to make more accurate silvicultural and operational recommendations.

Because of the size and complexity of this natural forest we are dealing with in Northern Maine, it is almost mandatory that we develop all available and pertinent information prior to making silvicultural or operating decisions. We believe this system under development will provide that information.

III ADMINISTRATION OF OPERATIONS

A viable forest management organization to structure the forest, the operations and its people is one important phase; vital and pertinent forest stand information is certainly another; but the actual operation itself - the planning, harvest, transport, and conversion of products, road construction, fire protection and forest practices - is the pay-off and the culmination of the process.

There are many planning and operating areas which we consider important and critical to intensive silvicultural development.

Some of those most important to Great Northern are:

(1) - Research

(2) - Road construction

(3) - Logging systems

(4) - Silvicultural criteria

(1) Research: The principal and first new position created in order to accelerate our development of intensive silviculture was that of Research Forester. The objectives of this position are in the field of applied research, to test and implement improved silvicultural techniques in our softwood types. Our emphasis to date has been in the area of regeneration. We have a pilot greenhouse and planting program underway.

(2) Road construction: The very wording "intensive culture" implies travel access to, and on the land in order to apply silvicultural practices. In 1904 the U. S. Bureau of Forestry recommended a 53 year cutting cycle for Great Northern; by 1955 P. K. Patterson, then Superintendent of the Division of Forest Engineering for Great Northern Paper, recommended a 30 year cutting cycle for the ensuing 10 year period. In 1976 we are realistically planning on 20-30 year cutting cycles where possible and feasible under the selection system. By 1986, certainly with the virtual completion of road systems onto GNP townships, we should

be able to consider 15 and 20 year cutting cycles in nearly all areas where we are applying a selection system or uneven-aged management.

Intensive silviculture on large forest ownerships depends on a well designed and economical transport system.

(3) Logging systems: So closely is logging and harvest technology wedded economically, and dependent on the tree and the lan that we may assume they act and interact as one total and integrated system. To consider silviculture apart from the techniques, the machines and the men who work the forest, who actually conduct the harvest, is to deny this integration and to forfeit its benefits.

The forest which Great Northern harvested in 1945-1955 was i large measure influenced and created by the men and logging technology of the early 1900's. The forest stands which we are harvesting today were created for us by the men and machines of the 1940's and 1950's; and we also are creating anew, the forest for the loggers and forest managers of the 1990's and 2000's.

Great Northern, in its own logging development, (T. A. Wildman Logging Engineer) is actively engaged in seeking out and testing those machines and systems which have the flexibility and capability of many and varied silvicultural applications - clear-cutting, thinning, timber-stand improvement, site preparation an planting. The wheeled skidder itself of course is a remarkable forest machine which has been specifically developed over the past 15 years by foresters, loggers and logging engineers - the economic benefits for forest industry have been substantial.

(4) Silvicultural criteria for Intensive Management: The criteria for tree harvest on an extensive basis in our spruce-fi types has been varied over the 75 year period. We have noted th original forestry cutting recommendation by the Bureau of Forestry as 12" on spruce and 6" on fir. This criteria was not followed - in the heavy budworm salvage years and afterward into th 1930's, stocking on GNP lands was so reduced that operations wer conducted in stands containing only 4-5 cords per acre of spruce and fir. In 1955, however, GNP set overall diameter limits of 8 on spruce and 6" on fir for its cutting policy. In 1963, long range cutting programs (5 year) were outlined using a 10" minimum diameter class (DBH) on spruce and 6" on fir to backup on-going marked selection cuts in spruce-fir stands. These criteri since 1955 have been generally followed in stands where application was feasible.

Great Northern, in its current program to intensify forest management on its forest lands, will establish cutting standards and criteria on a stand basis, with the overall responsibility for setting standards and controlling silvicultural practices delegated to district forestry staffs.

Specific criteria

(a) Stocking: We have accepted the basic guidelines and goals for spruce-fir stands as developed by the Maine Chapter of the S.A.F. in their recent publication "Forest Practices, Goals and Standards", issued in December 1973.

(b) Cutting cycles: On those areas and stands where a selection system (uneven-aged managment) is deemed feasible we are recommending a 20 year cutting cycle. Our previous projected cutting cycles for 1955-1975 had been based on 30 years. In this instance, of course, stand condition and road systems have been a principal determinant.

(c) Spruce budworm salvage: In our efforts to respond to the damages and losses due to the spruce budworm we have also had to set some basic criteria. In selection cuts we will harvest fir to a 6" minimum diameter. In stands to be clear-cut for salvage/pre-salvage operations, a minimum volume/basal area of fir of 30% has been chosen as an initial guide.

All spruce-fir stands, of course, are assessed and rated on a priority basis for current and prospective budworm damage. Operating plans are based on this assessment.

The above silvicultural criteria are an indication and example of our overall approach to a more intensive management system. We find ourselves in the midst of this planning process and a great deal remains to be done.

Conclusion: Great Northern is developing and intensifying its forest management by a careful step-by-step approach, based on assignment of forestry responsibility directly to the forest practitioner, by building a good resource information system, and developing administrative procedures which more closely integrate the total forest activity cycle of regeneration, growth, and harvest.

In closing I should like to respond briefly and directly to Mr. Hodge (in absentia) from the U. S. Bureau of Forestry. His final recommendation and dictum to Great Northern Paper in his report of 1904 was as follows:

FORESTER

"It is recommended that the Company employ a forester permanently, whose duties shall be: To decide what areas should be cut; to supervise the marking of trees; to *inspect* and *criticize logging* contracts; to supervise the protection of the tract - - - -"

To Mr. Hodge: Great Northern Paper has hired a forester - several of them, in fact, whose duties are substantially as you have recommended. We hope to achieve, in time, a forest management program as well conceived as the original working plan which you developed for us in 1904.

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[1] M. C. Hodge Jr., "Working Plan for Penobscot Timberlands-GNP Co.", 1904.

[2] Kwen M. Du and L. O. House, "Woodlands Information and Plannin System," *Systems Analysis and Forest Resource Management*, ed. J. Meadows, et al, (Bethesda, Maryland: Society of American Foresters 1976), pp 427-32.

SMALL WOODLAND OWNERSHIP MANAGEMENT

by Albert J. Childs, SRA, RPF, President, Eastern Forest and Land Management Company, a Division of Eastern Appraisal Company, Portland, Maine

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Small woodlot ownerships are a commodity on the real estate market which have cycled through a supply and demand curve on a somewhat irregular basis. In order to have some understanding of what it is we are talking about, it is necessary to define what a small woodlot is, and where it may be found. In size these parcels can range from ten acres to fifteen acres on up to fifteen hundred acres to two thousand acres. Geographic locations encompass the entire Northeast. Most of our our larger communities encompass a few forest production parcels within their municipal boundaries, and these are the properties that we see being developed yearly for commercial and residential purposes. The outlying urban and rural areas of the organized communities have their land base created almost entirely by these tracts. The magnitude of this forested area is startlingly apparent when you fly over the Northeast and see the relatively small amount of land intensively developed as opposed to woodland acres.

If we have all of this forest land on the face of the earth, then who owns it and what are they doing with it? At this point we enter into the real problems and address the challenge to the managing forester. Land ownership patterns have been changing since Columbus made a right turn at the Azores and landed on our shore. From that time forward the scribes, lending merchants, lawyers, and real estate brokers have done a tremendous job in complicating the management of our small woodland parcels. In recent years probably no faction has had more influence on the existing ownership pattern than real estate brokers and entrepreneurs, with considerable help from environmental groups along with the declining stock and bond market.

The real estate brokers and entrepreneurs have tracts of land in all sizes for a variety of reasons. While most statistical surveys use a so called average buyer or average real estate owner, I have yet to see or truly identify with that individual. In our business the average land owner does not exist and each propert owner is an individual in his own right with individua motivations and opinions. A forester who thinks otherwise may be headed for a real public relations problem to say nothing of managerial and legal problems. Some consistent characteristics of small woodland owners do appear quite frequently such as: 1) principal employment is of the skilled or professional field, 2) woodland properties are acquired primarily for investment either on a short term or long term basis, 3) initial acquisition is generally made during a period of time when the owner's personal financial situation is optimistic, 4) typically there is no comparative investmen analysis made by the buyer with other forms of investment prior to acquisition. Again, it should be pointe out that these are only characteristics frequently see or discussed with small woodlot owners and are not a statistical conclusion, but rather an observation.

With all of this as background we can now discuss management philosophy and goals. A basic philosophy for the management forester must come primarily from the owner's attitude and reasons for ownership and ultimat objectives to be accomplished through land management. The most frequently discussed objectives of ownership include conservation, generation of periodic income, or capital gains to be derived through real estate appreciation and ultimate sale of the property in gross. An individual who owns property for conservation purposes offers an opportunity to manage a parcel of land on a relatively long term basis, with the least probability of disruption through sale of the property. Th second form of ownership objective, namely the generation of an income stream, is probably one of the most tenuous because the income that can be derived from a small woodlot is going to be periodic at best. In mos cases it will not offset actual cash carrying charges if the property was acquired at current fair market value with a debt service requirement and return on equity desired. This is not to say that a small woodlot parcel cannot be managed on a profitable basis when long term appreciation and capital gains are considered, but rather that foresters managing lands owne primarily for their income generation potential should be cautious in their goal setting procedures and not extend them out over a long period of time.

Quite frequently owners who are looking to an income from the land for repayment of debt or purchase monies may find themselves in a position where sale of the property is necessary due to a change in their own personal finances. This can be caused by a change in other financial circles that has nothing to do with the land on which the forester is working. The third category of land ownership is the objective of a capital gain to be received by the owner at some future date when the land is sold in gross. This form of ownership objective offers some variables to the general management scheme. The forester must be aware of changing land uses in order to orient his harvesting and management practices toward a form of use that will increase the overall property value as required by the owner. Again, we must be prepared to recognize that management of lands held for this purpose could quite reasonably be of relatively short duration and that probably a conversion of use is anticipated at some future date.

After considering the various objectives of the land owner a forester must then examine his property for development of the management policy and method of achieving the basic goals. Properties owned for conservation purposes lend themselves to the standard silvicultural practices where TSI (Timber Stand Improvement) or harvesting of merchantable timber is indicated. Here in the Northeast it is extremely difficult to justify TSI on all but the highest quality species and stands if the economics and financial requirements are considered on an investment basis. A managing forester must have a working knowledge of cost accounting to include calculation of debt service on the land, return to equity investment, and the incremental additional charges for interest on invested capital for supplemental improvements. TSI is a capital improvement to the land and should be treated as such for capital gain accounting purposes as well as the need to know what your actual costs are to produce a given volume of work.

In cases where a capital gains objective is the purpose for ownership, the forester must be aware of short range costs deferral methods. His management plan must be geared to abstract from the land the maximum goods or services on a short run basis without deminishing the owners potential for profit at some future date. This form of planning requires a rather extensive knowledge of general land uses in the immediate area of your management property and should include a general knowledge of regional and national affairs affecting the real estate market.

It is wise to be prepared for the unexpected, and hence a "bust" program should be devised for each such parcel in the event that the owner becomes financially shaky This event may require immediate working capital derived through the sale of the managed property. In order to be prepared for such an event, and to proper prepare a medium to long range management plan, it is necessary that the forester be familiar with marketin strategy for both products and the land itself. Real estate, which is the item a forester is managing, is not classically known as a liquid asset. In other words, you cannot predict with any degree of certaint the exact length of time it will take to sell a particular parcel of land at its market value. It is even difficult to predict how long it will take to sell a parcel of land at liquidation prices. In order that forester be relatively familiar with time segments required for marketing, a constant vigil must be kept o the activity of the general real estate market and wh is dealing in it.

Another relatively recent problem which confronts the managing forester is the changing environmental and zoning codes initiated by all levels of federal and state government. These codes not only affect the way and procedures by which the land can be managed, but also has a decided effect on the economics of forest land ownership. In recent years we have seen productive timber land removed from the productivity classifications without any reimbursement to the land owner merely on the basis of environmental safeguards. Thi form of zoning and loss of revenue production propert may, at some future date, be pronounced an environmental taking similar to the eminent domain proceedings commonly used throughout the land. However, today we must live with, and manage, the small woodlots under an ever-increasing restrictive public policy. An awareness of land law and environmental law is an absolute must for the professional forester in order to advise his client on the affect of such law, and to explain why his income producing base has diminished. With the unquestioned fact that real estate taxes, ca rying costs, and demand for forest land for other purposes is on the rise will unquestionably make the managing forester's job more challenging and more profitable to himself. Small woodland management is merely the implementation of what is commonly called the Six "P" rule, i.e., "Prior Planning Prevents Piss Poor Performance."

EFFECTS OF TAXATION ON THE PLANNING AND IMPLEMENTATION OF INTENSIVE TIMBER MANAGEMENT

by David B. Field, Associate Research Professor, School of Forest Resources, University of Maine, Orono

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Abstract

Taxes on forest properties and on income from timber disposal impose one of the most significant kinds of cost burden faced by owners of interests in forest lands. Local property taxes impose annual charges regardless of the level of management, and may even be increased by intensive practices. Federal and state income taxes are usually second in impact only to property taxes. Federal transfer and state death taxes can seriously endanger the continuity of management programs from one generation to another. Taxpayers can significantly reduce the impacts of these taxes by an awareness of the advantages and pitfalls in each as they apply to timber management.

DESPITE THE FACT that many economic analyses of timber management options omit tax considerations as being "too complex" or "too variable", an oversight or error of judgement in this area can have a far greater impact on the profitability of a venture than will an error in many of the elements of analysis on which a great deal of effort is usually expended. Timber owners judging the desirability of intensifying management practices may fail to take adequate account of probable tax impacts and may fail to recognize readily avoidable pitfalls or available tax advantages. This paper offers a synthesis of the rules and effects of the major taxes faced by forest land managers, of both large and small ownerships, with respect to decision-making on matters of intensive timber culture.

TAX LAW FUNDAMENTALS

Taxes imposed on forest landowners include: 1) income taxes, 2) general property taxes, 3) transfer taxes, and 4) sales, excise, and other special levies.

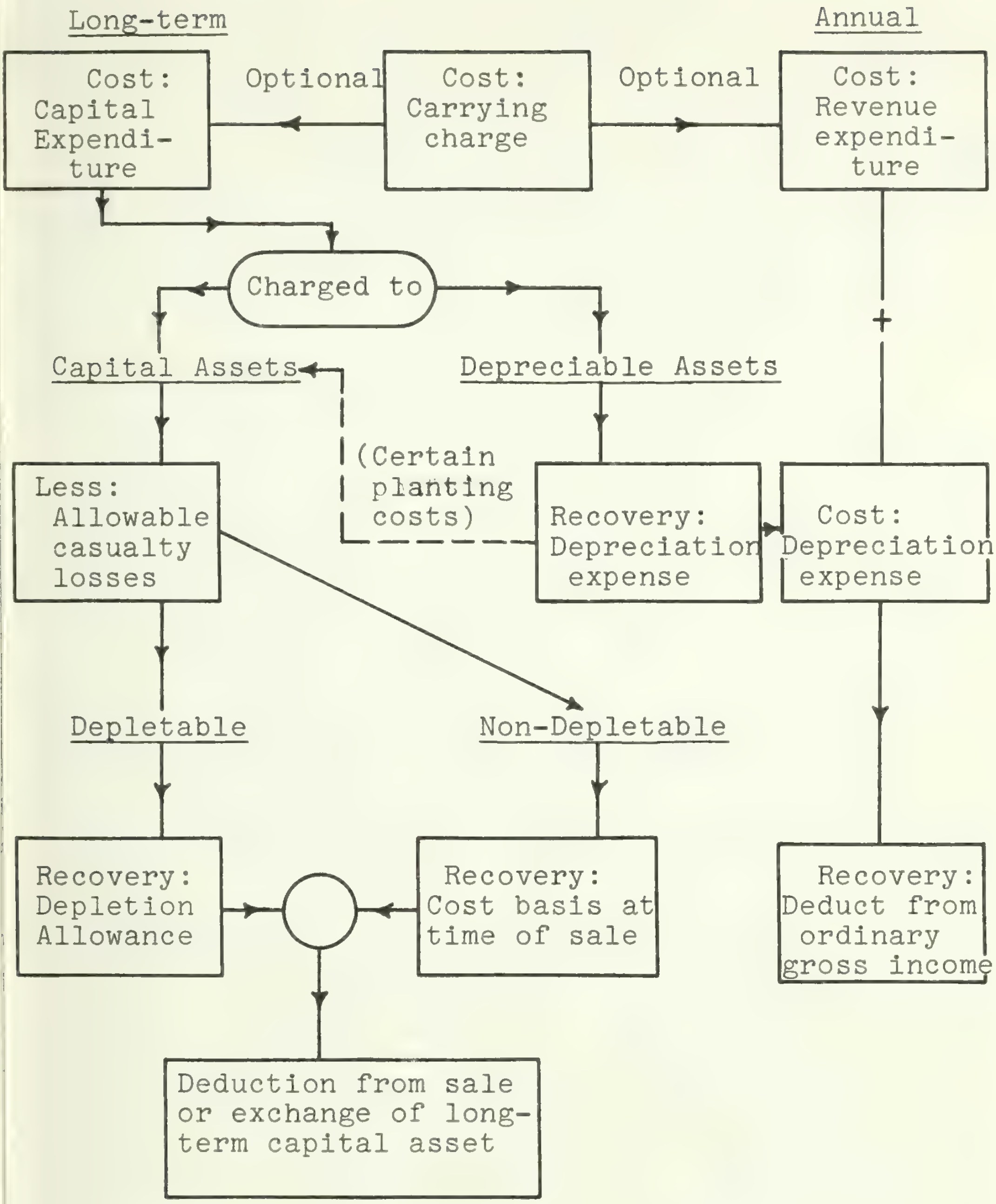
Special taxes can be substantial, as those paying Maine's spruce budworm charges of 28¢-56¢ per acre would be quick to agree. However, with the possible exception of that complex and still-evolving scheme, special taxes tend to be rather stable and show little change in impact under different management decisions. The remainder of this paper concentrates on the other three types.

Federal Income Taxes

One of the most important tax burdens faced by a forest landowner in the United States is the Federal income tax. Individual taxpayers face a levy (1975) of from 14% to 70% of their adjusted gross income. Corporations pay 20% of the first $25,000 of taxable ordinary income plus surtaxes that increase the rate on the next $25,000 to 22% and on amounts over $50,000 to 48%. (These rates resulted from the Tax Reduction Act of 1975. Unless that law is extended, corporate rates will revert in 1976 to the former levels of 22% of the first $25,000 plus a surtax of 26% of income in excess of $25,000.)

The Federal income tax is levied on *net* income, that is, on the proceeds of an investment or business venture less the costs of earning those proceeds. The basic idea is that you should not be taxed for income that simply replaces costs of earning that income. Deductible costs include annual outlays for the "ordinary and necessary" expenses of carrying on a trade or business, gradual recovery of investments in long-lived assets, and expenditures for the carrying charges, such as taxes and interest, of holding a business property. Individuals, moreover, may deduct from their ordinary income, from all sources, ordinary and necessary expenses for the production or collection of income, or for the management, conservation, or maintenance of property held for the production of income, even though no formal trade or business is involved.

The ways in which the costs of forest ownership and management may be recovered, for tax purposes, are outlined in Figure 1. Three kinds of expenditure may be involved: 1) capital expenditure, 2) revenue expenditure (expense), and 3) carrying charge. Capital expenditures are costs of acquisition of long-lived property or property rights, or permanent improvements that increase the value or extend the life of property already owned.



Long-term
Annual
Cost: Capital Expenditure
Optional
Cost: Carrying charge
Optional
Cost: Revenue expenditure
Charged to
Capital Assets
Depreciable Assets
+
(Certain planting costs)
Less: Allowable casualty losses
Recovery: Depreciation expense
Cost: Depreciation expense
Depletable
Non-Depletable
Recovery: Depletion Allowance
Recovery: Cost basis at time of sale
Recovery: Deduct from ordinary gross income
Deduction from sale or exchange of long-term capital asset

Figure 1. Recovery, as Federal income tax deductions, of the costs of forest ownership and management.

Such assets are classified under tax law as either depreciable or capital. Depreciable assets are defined under Section 167 of the Internal Revenue Service (I.R.S.) 1954 Code as property with a limited and determinable useful life of more than one year which must be used in your trade or business or be held for the production of income. Investments in such property are recovered through a gradual writing off of their cost against ordinary income as the assets wear out or become obsolete. (The term "amortization" is commonly used to refer to the depreciation of intangible assets such as management plans and maps.)

Capital assets are defined by exclusion in Section 1221 of the 1954 Code as any property held by a taxpayer (not necessarily a business property) except: 1) stock in trade or other inventoriable property, 2) property held by the taxpayer primarily for sale to customers in the ordinary course of his trade or business, 3) Section 167 depreciable property used in the taxpayer's trade or business, or real property so used, and 4) accounts or notes receivable acquired in the ordinary course of a trade or business. Investments in capital assets can be recovered only when the assets ar disposed of. Costs of "wasting" capital assets, typified by natural resources such as timber and minerals, are recovered by deducting, from disposal proceeds, a pro rata allocation (termed "depletion") of that cost to the units removed from the property, as allowed by Section 611 of the 1954 Code.

Federal income tax law includes three major tax reduction incentives designed to encourage investments in long-lived assets, on the assumption that such investments are beneficial to the health of the national economy. None of these provisions were created to encourage forestry specifically--they apply to all business and other income-producing ventures--but their influence is of great importance to the timber owner. I will discuss, in turn, accelerated depreciation, the investment credit, and the preferential treatment of income from the disposal of capital assets.

Accelerated depreciation. Straight-line depreciation is the regular deduction, from ordinary taxable income, of an equal portion of the cost of a depreciable asset (less any estimated salvage value) over the expected life of that asset. To encourage reinvestment, Federal law allows taxpayers to accelerate the deprecia tion write-off by as much as twice the normal rate. Moreover, certain kinds of personal property qualify for a first year deduction of 20% of cost in addition to regular depreciation.

Investment credit. An income tax credit can be a far more significant incentive measure than an expenditure deduction. The latter simply reduces taxable income, hence lowers tax payments only by a multiple of your tax rate. A credit, on the other hand, is a direct deduction from the tax liability itself. The investment credit is applicable to depreciable property with an estimated useful life of three years or more and to "qualifying progress expenditures". Property covered by the credit includes, in part, tangible personal property used as an integral part of manufacturing, production, or extraction activities. Qualifying progress expenditures are amounts actually paid for the construction of these kinds of property if such property has a normal construction period of at least two years and an estimated useful life of at least seven years. The investment credit allows a deduction from your tax bill of 10% of the cost of a qualified investment in covered property for the year in which that property is placed in service, or for 20% of the full amount of qualified progress expenditures made in that year. A qualified investment is one-third of the cost of new or used property with an estimated life of three to five years, two-thirds of the cost of new or used property with an estimated life of five to seven years, and the full cost of property with a useful life of seven or more years. (The full value of used property claimed cannot exceed $100,000.)

Capital gains. Gains or losses from the sale or exchange of capital assets are granted special treatment for tax purposes. This incentive takes the form of a special exclusion for individual taxpayers and a preferential rate for corporations. A capital gain is the excess over the adjusted basis (usually book value) of the amount realized from the disposal of a capital asset. Such a gain is either long-term or short-term, depending on whether the asset has been held for longer than a required holding period (currently six months). If an individual taxpayer's net long-term capital gain exceeds his net short-term capital loss, he may claim as a tax deduction 50% of the difference. This exclusion applies regardless of tax bracket. Thus, the effective tax rate on an individual's net long-term capital gains is only half that of his ordinary rate.

An individual is entitled to calculate his tax liability in two alternate ways, and to pay according to the approach which yields the smallest tax. By the first method, no tax at all is paid on 50% of the long-term capital gain and ordinary tax rates apply to the balance. In the alternate computation, a taxpayer whose net long-term capital gains do not exceed $50,000 may take the 50% capital gains deduction, compute a partial tax on the residual taxable income, then add 50% of the capital gains deduction to the result, for a maximum effective tax rate of 25%. Taxpayer's with net long-term capital gains of greater than $50,000 may use an alternate computation which, in effect, taxes the first $50,000 at 25% and the balance of the gain at higher rates (maximum of 35%).

The tax rate on net corporate long-term capital gains is a flat 30%. Corporations may also calculate their tax liability in two ways and pay the lesser of the two. The regular tax is found simply by applying the regular rate to total taxable income. The alternate tax is calculated in two steps: 1) Apply the regular tax rate to total taxable income, less the excess of net long-term capital gain over short-term capital loss. 2) Apply the capital gains rate to the long-term capital gain. The alternate tax is the sum of these two. Whether a corporation benefits from the preferential capital gains rate depends on its tax bracket and the relative amounts of its capital gains and net ordinary income.

Clearly, Federal income tax law offers some powerful incentives for long-term capital investments. But, there are two considerations which moderate the beneficial effects. First, current tax law levies a surtax on both individuals and corporations for "tax preference items" in excess of $30,000, less certain deductions. These items include amounts claimed for accelerated depreciation in excess of allowable straight line deductions, and capital gains allowances. Secondly deductions for capital expenditures may be used to offset capital gains income only, and may not be charged against ordinary income. Thus, they reduce tax liabilities at capital gains rates rather than the usually higher ordinary rates. This is a key point to keep in mind in the discussion of the effects of Federal income taxes on forest management, presented later.

State Income Taxes

State income tax laws vary so greatly that I will comment only on Maine's law, by way of example. Corporations are taxed 5% of the first $25,000 of Federal taxable income apportioned to Maine (adjusted for Federal tax allowances specific to Maine) and 7% on the excess over $25,000. Individuals, estates, and trusts will pay (for 1976) at rates of 1% to 8% on Federal adjusted gross income (adjusted further for differences between Maine and Federal allowances). An income-splitting provision for married taxpayers filling jointly reduces the effective rate substantially. The rates will go up in 1977.

Property Taxes

Property tax laws vary so much from state to state as to make a comprehensive summary beyond the scope of this paper. From the viewpoint of effects on intensive timber management, the most important types of property tax laws are the conventional ad valorem taxes on land and timber together, yield taxes, productivity taxes, current use laws, and the myriad of special rebates, exemptions, and other direct subsidies which have been tried from time to time to achieve specific forestry objectives.

Transfer Taxes

The Federal government taxes both gifts and bequests. Nearly all of the states impose both an estate tax and an inheritance tax. The Federal transfer taxes are really neither taxes on property nor on a beneficiary or donee's right to receive property. They are excise taxes on the rights to transmit property at death and by gift (Anonymous, 1963).

Federal estate tax. The estate tax is levied on the value of all property, to the extent of the decedent's interest at the time of his death, less certain deductions and exemptions (U.S.D.T., I.R.S., 1971) The gross estate includes all property which passes through the estate, property over which the decedent retained certain rights until his death, and transfers "in contemplation of death". The taxable estate is the gross estate, adjusted for expenses of and claims against the estate, and reduced by a marital deduction (the lesser of 50% of the adjusted gross estate and the value of all interests passing to the surviving spouse that qualify under I.R.S. rules), a deduction for charitable bequests, and a specific exemption of $60,000. The gross estate tax is calculated on the amount of the taxable estate at a rate varying from 3% (for up to $5000) to 77% (for taxable estates over $10,000,000). The tax actually paid is the gross estate tax less: certain credits for state death taxes, Federal gift taxes on property subsequently included in the decedent's estate, and Federal estate taxes on property bequeathed to the decedent within certain time limits of his death.

Federal gift tax. The Federal gift tax is a levy (upon the donor) imposed upon the value of property or property rights transferred by gift. The tax applies to the total value of the gifts, less: an exclusion of $3,000 of gifts made to any one person during any calendar year, a specific exemption, and a marital deduction. A lifetime exemption of $30,000 is allowed and may be spread over time as the donor sees fit. The marital deduction, in effect, allows a maximum annual gift of $3,000 to a spouse in addition to the $3,000 exclusion. Spouses may pool their allowable deductions in donating to a third party. The tax actually paid is calculated on the taxable gifts at a rate varying from 2.25% (for up to $5,000) to 57.75% (for taxable gifts over $10,000,000).

State death taxes. Most states impose both an inheritance tax (levied on the beneficiaries rather than the estate) and an estate tax. The latter is usually designed simply to obtain for the state the benefit of the credit allowed under Federal estate tax law for state death taxes paid. Maine's inheritance tax, applicable to much the same transfers and kinds of property as the Federal estate tax, recognizes several classes of inheritors, based on closeness of relationship to the decedent. For closest relations, the tax rate varies from 5% on taxable inheritances of less than $25,000 up to 10% on inheritances of $250,000 or more, with exemptions of $50,000 for spouses and a total of $25,000 in the case of natural or adoptive parents and natural or adopted children and grandchildren.

INTENSIVE MANAGEMENT OPTIONS

What do we mean by "intensive timber management"? Obviously, the term can cover a wide range of practices and levels of treatment, but we might reasonably view its scope as including any effort over and above the periodic extraction of timber grown with no deliberate management at all. I will outline the possibilities under five categories: 1) the resource base, 2) stand establishment, 3) stand management, 4) forest management, and 5) indirect influences, with emphasis on topics especially influenced by taxation.

The Resource Base

Management decision associated with land, the forest resource base, may be listed in four categories: 1) land acquisition, 2) land inventory, 3) land development, and 4) land disposal.

From the viewpoint of social welfare, public benefits can result from any acquisition, in fee or in partial right, of bare or poorly-stocked forest land, by an individual or organization determined to actively manage that land for timber. Such activities represent intensification of management of forest lands in general.

Acquisition of stocked forest land, or rights to that land and timber, may also represent an intensification of the level of management on such land. This country's many years of experience with and study of "the small woodland problem" suggest that an aggregation of fragmented parcels into larger management units may offer one of the more promising opportunities for significantly improving the management of those lands. A few successful cooperative associations of landowners themselves exist, but the greatest promise may lie in the leasing of lands from small landowners to block them up into more effective management units under the control of long-lived legal entities with a vested interest in productive timber management.

The device of acquiring partial, rather than full legal interest in land and/or timber may serve the cause of intensive management regardless of the nature of the landowner. The lower capital investment requirements of such arrangements can make affordable practices that would not be possible in cases of fee acquisition.

Information about the resource base is a fundamental prelude to any kind of intensive management. Planimetric surveys, topographic surveys, soils surveys and site mappings of varying intensities may be involved in the land inventory portion of the management program.

A third area of interest associated with the forest land base is land development. Intensive management of timber stands requires access and support facilities. Extending and improving road networks affords access for cultural work and more careful harvesting. Although rare in the Northeast, intensive management in the Lake States and Scandinavia has included land drainage activities.

Finally, a persistent problem of both large and small non-corporate woodland management is that of maintaining continuity from generation to generation. Poor estate planning can force liquidation of family interests in a given land parcel, or premature harvest of timber on that parcel. A carefully-planned forest may be forfeited to pay death taxes that could have been avoided.

Stand Establishment

Management decisions associated with forest regeneration may also be listed in four categories: 1) species selection, 2) genetic tree improvement, 3) site preparation, and 4) methods of sowing, planting or natural regeneration.

The opportunities for intensifying timber management in the area of stand regeneration are many. So far as taxation is concerned, the question of fundamental importance is whether regeneration is artificial, natural, or a combination of these (e.g., site preparation with natural seeding).

Stand Management

Timber stand management options may be listed in three categories: 1) cultural activities, 2) silvicultural systems, and 3) rotation age decisions.

Cultural activities (weeding, thinning, pruning, fertilizing), along with artificial regeneration, are the paths along which most landowners embark upon intensive timber management.

Silvicultural systems blend consideration of site capability, species choice, regeneration method, product goals, and harvesting economics into prescriptions for individual stand management. Attainable rotation ages can be strongly influenced by intensive management. Taxes are reflected in desirable rotation limits.

Forest Management

Management decisions associated with forests or groups of forest properties may be summarized in four categories: 1) forest inventory and analysis, 2) forest protection, 3) harvest planning and management, 4) timber disposal.

Along with land inventory, a forest manager needs a comprehensive forest inventory system. Information from these inventories may be studied through conventional methods, and by simulation and optimization analyses based on stand and forest models, to develop management plans for individual stands or types, forests, and entire ownerships. Forest protection, through fire prevention and suppression, and insect and disease control, can vary over a wide range of intensity. Harvesting planning must consider long-range impacts on production possibilities, utilization intensities, and salvage of dead or damaged timber. Timber disposal, by use of roundwood in the landowner's own mill, sale of stumpage, sale of logs, or transfer by gift or inheritance, involves taxation effects that can greatly influence the profitability of that disposal.

Indirect Influences

I stopped the management option list at the forest level in order to focus on matters of primary concern to this symposium. However, neither the individual nor the corporation can afford to analyze the impacts of taxes on forest management decisions in a vacuum. The small woodland owner should constantly be aware of the interactions of these decisions and such matters as his other sources of income, his other business activities, and his estate. Ideally, integrated forest products firms should consider interactions within their whole corporate system. For example, land and timber acquisition decisions should not ignore other wood-source options, nor should an optimum rotation question be studied independently of the timing of mill wood needs. In practice, intelligent judgement seeks the point where the benefits of decision option analysis outweigh the costs.

You should also keep in mind that the effects of taxation on landowners directly are certainly not the only way in which taxes influence management intensity. All costs of harvesting and processing roundwood through to the consumer can influence timber management options throughtheir impact on residual stumpage values. Any knowledge of tax law which allows a reduction of these costs can be beneficial to timber management.

Public forest management, also, can be influenced by tax law in at least three ways: 1) pressure for higher payments to local towns in place of property taxes, 2) Federal capital gains treatment of revenues from National Forest stumpage sales, and 3) the effects of yield taxes on the behavior of loggers harvesting public stumpage.

EFFECTS OF TAXATION ON INTENSIVE TIMBER MANAGEMENT

Let us now see how the various taxes affect the comparative economics of the intensive management options just listed.

Effects of Income Taxes in General

All income taxes, Federal, state, or local, will affect rotation decisions variably, according to the tax bracket and other financial circumstances of the taxpayer. They may shorten or lengthen the rotation, depending on these conditions. Capital gains tax provisions tend to lengthen optimum economic rotations (by comparison with ordinary income taxes) under all circumstances. These effects result from the fundamental criterion underlying the economic rotation decision: So far as mill wood needs or cash flow requirements allow, it makes sense to hold a stand of timber so long as one more year's earnings on growth and/or value appreciation exceed one more year's costs of holding and managing that timber. Income taxes, by reducing net earnings, cause this point in time to be reached earlier than would otherwise be the case. But, preferential capital gains taxation allows a longer rotation than do ordinary income tax rates.

Effects of the Federal Income Tax

My outline of Federal income tax law should have made it clear that it is to the landowner's advantage to try to ensure capital gains treatment of as much of his income as possible, and to try to make as much of his expenditures as possible qualify for deduction against ordinary income.

Keys to the first of these two goals lie in Sections 1221, 1231, and 621 of the 1954 Code. Because Section 1221 excludes from the definition of capital assets any "property held primarily for sale to customers in the ordinary course of his trade or business", disposal of timber for a lump sum price by a dealer in timber properties results in an ordinary gain or loss. But, timber held for investment and not as a business property is a capital asset and qualifies for capital gains treatment. Moreover, Section 1231 states that if the gains on disposal (by sale, exchange, or involuntary conversion such as destruction or theft) of property that is used in a trade or business exceed the losses from such disposals, then both the gains and the losses shall be treated as capital gains and losses regardless of Section 1221. If the losses exceed the gains, both are treated as ordinary. Section 1231 further specifies that timber to which Section 631 applies is defined as property used in the trade or business for the purposes of Section 1231 treatment.

Section 631 (which affords capital gains treatment to timber only through the reference from Section 1231) defines gains and losses under certain kinds of timber disposal. Section 631(a) specifies that one who has owned or held a contract right to cut timber for a period of more than six months before the beginning of the year in which it is cut, and who cuts the timber for sale or for use in his own business, may elect to treat the cutting as a sale or exchange of standing timber. The gain on this fictitious sale is the difference between the cost basis of the standing timber in the taxpayer's hands and the fair market value of that timber as of the first day of the taxable year in which it is cut. Section 631(b) specifies that, in the case of a disposal with a retained economic interest of timber held for more than six months, the difference between the proceeds from that disposal and the adjusted depletion basis shall be considered as though it were a gain or loss on the sale of the timber. The key to retention of an economic interest is that the income on the sale must depend on the severance of the timber and the payment must be on the basis of the amount actually cut.

The conclusion to be drawn from these sections of the Code is that net timber disposal proceeds--the basic aim of and source of funding for intensive management--can be markedly affected by the nature of the sale arrangements and management activities. Several details are worth further consideration.

Intensive harvesting. Consider intensifying management through increased tree utilization. If you plan to sell tops, limbs, stumps, and/or roots, do so at the same time as the rest of the tree is sold. 631(b) applies only to the disposal of standing timber. 631(a) applies only to the whole tree standing. Sales of residual material after the fact will be treated as ordinary, not capital in nature.

Leases. Lease arrangements must be handled carefully for tax purposes. The lessor should try to retain an economic interest in the timber, in order to qualify for capital gains treatment under Section 631(b). The lessee, on the other hand, should try to obtain a sufficient legal interest in the timber to qualify for the use of Section 631(a) and sufficient interest in the whole property to be able to expense, rather than capitalize, management costs. Generally speaking, it is not possible for both parties to satisfy these interests simultaneously, so the tax effects of a lease agreement can be an important issue in the bargaining process.

Litigation over leasing and other long-term cutting arrangements was summed up, from the lessor's viewpoint, in Revenue Ruling 62-81 and the basic court findings of the Dyal Case in 1965 (Fendig, 1966): 1) A taxpayer is not entitled to capital gains treatment under Section 631 for fixed annual payments to be paid regardless of cutting. 2) A taxpayer is entitled to capital gains treatment for timber sold on a scale basis according to the amount actually cut. 3) Regardless of whether an economic interest is retained, a taxpayer is entitled to claim capital gains treatment to the extent of the fair market value of the timber on the land at the time the leasing agreement is made. This third circumstance is the only one for which the courts have ruled that the lessor may claim a 631(b) sale even though the lessee is allowed an ordinary expense deduction for the rental fee. In effect, the "sale" (by virtue of the lease) of the initial timber stand is treated separately from the long-term management and harvesting of subsequent growth. Then, the lessee is entitled to ordinary deductions for rental fees and management costs only, in the opinion of Landis (1966), if: 1) he has a possessory interest in the land, not just annual cutting rights; 2)there is a clear limitation of cutting rights to annual growth, or some other device which separates payment for timber on the land at the outset from later annual payments; and 3) the payments must be made regardless of whether the timber is actually cut or even available for cut.

Deductible expenses. The question of which timber management expenditures may be deducted from ordinary income and which must be capitalized, to be recovered through depreciation, depletion, or sale of the asset is covered in Sections 161,162, and 263 of the 1954 Code, applicable to all taxpayers, without specific reference to forestry. Particular concerns have been answered in large part by many years contention between taxpayers and the Internal Revenue Service. The results are of great importance to intensive management interests. In particular, *all* direct costs (including depreciation of equipment used) of artificial regeneration must be *capitalized* and can be recovered only through the gradual allocation of the depletion process as the mature timber grown from that regeneration is harvested (or immature or mature timber is destroyed by a natural disaster). When you are pondering the relative merits of natural versus artificial regeneration, you must keep this requirement in mind.

Internal Revenue Service reasoning on these matters is often difficult to predict. Foresters familiar with I.R.S. requirements to capitalize planting costs have reasoned that Forestry Incentives Program cost-share payments should be treated as reductions from capital expenditures and entered in the depletion account. For example, amounts for planting costs would be reduced by the amount of the government reimbursement. But, I.R.S. representative have contended that FIP payments must be treated as ordinary income. Moreover, the I.R.S. advises that the *entire* expense, both the landowner's share and the government's, should be capitalized and recovered through depletion. This treatment "effectively reduces the maximum cost-share payment from the 75 percent intended by Congress to about 52 percent for an average landowner." (Bethune and Fortson, 1975

The key to these decisions is whether an expenditure is an "ordinary and necessary" cost of maintaining an investment property, or carrying on a business, or is an expenditure that makes permanent improvements in or extends the life of a property. Thus, timber stand improvement expenditure are allowed to be deducted (*or* capitalized, at your option) only if they are part of a regular program of such treatment, followed consistently from year to year, hence an "ordinary and necessary" part of *maintaining* the quality of a timber stand. But, infrequent T.S.I. work may be challenged as fundamentally changing and improving the nature of a timber asset. In a famous case of the 1960's, the I.R.S. finally, at the direction of the courts, agreed to allow the expensing of pruning and shearing of Christmas trees, but only if those trees were planted and grown as Christmas trees from the start. If you prune and shear natural stock to *convert* it to Christmas trees, you will be required to capitalize the initial costs of those activities.

Carrying charges. Carrying charges, such as annual property taxes, interest payments, and protection costs, may be expensed or capitalized as you see fit. Research and experimental expenses may be deducted currently as business expenses, or amortized. Amortization is probably the proper treatment of purchased management plans, maps, aerial photographs, computer models, and so forth, though minor items in these categories may often be expensed.

Roads. Costs of permanent roads must be capitalized, except for depreciable components such as bridges, culverts, and surface gravel. Costs of temporary roads may be amortized over the term of their usefulness, either on a time scale or according to the units of timber harvested.

Cruises. Timber cruises for acquisition of a specific parcel of forest land must be capitalized into the book value of that property. Cruises for ordinary inventory and exploration of owned property may be expensed. You can try to expense the costs of cruises taken in connection with a 631(b) sale, but the I.R.S. will claim that such costs should be used to reduce the net gain on the sale, hence benefit you only at capital gains rates.

Investment credit. The investment credit can be a very significant incentive for intensive management. Perhaps the most important application, especially for larger landowners, is to logging road construction. I.R.S. Revenue Ruling 68-281 held that a certain taxpayer's logging truck roads qualified for the credit since they were an integral part of the operation of sawmills, the production of lumber products or other building materials, or the manufacture of paper (Anonymous, 1969). Whether the road is permanent or temporary, either the cost of the entire road or that of part or all of the depreciable portion may qualify for the credit, depending on the useful life of the portion in question.

In addition to logging roads, the investment credit would apply to many kinds of planting, T.S.I., and harvesting equipment.

Income averaging. The Tax Reform Act of 1969 added capital gains to the income that can be averaged by an individual under Section 1301 of the 1954 Code. This provision could be of significant help to a small woodland owner who makes sizeable, but infrequent timber sales.

Effects of State Income Taxes

The Maine income tax is patterned so closely after the Federal income tax that it can be viewed as a sort of surtax. It will have an effect on the profitability of a timber management investment, on decisions involving acquisition and disposal of timberland, and optimum rotation questions, but should make no differential impact on the outcome of different intensive management activities.

Effects of Property Taxes

James Yoho (1965) has written that there is simply not very much known about the influence of various property tax forms and levels on individual forest investment decisions, or on the magnitude and direction of aggregate forest investment decisions. It can be argued that high land values and consequently high taxes logically force landowners into intensive management in order to minimize the land base necessary to the production of a given volume of timber products. Indeed, it has been argued that intensive forestry is a necessity of coping with property taxes (Miralles, 1971). But, this effect can be overshadowed by taxes so high as to discourage timber management altogether.

General property taxes impose two kinds of cost burden on the forest land owner: 1) that of meeting annual cash flow demands and 2) that of holding costs. The first is especially burdensome to the small woodland owner, who usually does not have enough land to provide annual timber sales revenues to offset these taxes. The second influenc can affect both rotation length decisions and judgments on whether to maintain ownership of a given parcel of land. A landowner must be able to manage his property, if it is to be a profitable venture, in such a way as to generate time-adjusted earnings which will cover his property taxes (and other custodial charges), cultural activities, sales expenses, and overhead costs and, in addition, return at least as much as could have been realized on an investment of the same capital in an alternative venture (Field, 1976).

In general, any property tax which includes the current value of the timber crop in its assessment base will penalize intensive management by compariso with lower levels of management and will shorten the optimum economic rotation in the same manner as an income tax. In the case of a productivity tax such as Maine's Tree Growth Tax Law, however, improvements on growth and yield on individual properties would not affect tax rates until enough properties were so treated as to influence the large geographic areas over which growth rates are averaged.

At the very least, property taxes can absorb funds that would otherwise be available for investment in intensive management practices. Partly in recognition of this, many specific property tax exemptions, rebates, and other subsidy measures have been enacted over the years to encourage particular forestry practices. Cumbersome enrollment mechanisms, weakness of the incentives, and fear of local assessor reprisal have combined to make such measures largely ineffective. Large-scale present use and productivity assessments, which are based more on arguments for equity than for subsidy, appear to offer more promise of success in encouraging sound timber management.

I have already stressed the significant impact of income taxes upon the profitability of a forestry venture. It would be well, at this point, to place the relative impact of the property tax burden in perspective. Consider, for example, a private, noncorporate, forest landowner in the 20% Federal income tax bracket who is faced with a 50¢/acre/year general property tax on his land and timber. Suppose he establishes a tree plantation, at a total cost of $50/acre, which he expects to yield 40 cords/acre at the end of a 40-year rotation. Suppose, finally, that the stumpage value of the wood at that time will be $10/cord and that the landowner's cost of capital is 8% per annum. The Federal income tax on the sale of this timber in year 40 will be:

$$[(40\ \text{cords/acre})(\$10/\text{cord}) - (\$50/\text{acre depletion})] \times [(.50\ \text{capital gains deduction})(.20\ \text{tax rate})] = \$35/\text{acre}.$$

The value of annual property tax outlays, compounded to year 40 @ 8%, less the cash flow from annual deductions of these outlays against ordinary income for Federal tax purposes, also compounded to year 40 at 8%, is:

$$\$129.53/\text{acre} - \$25.91/\text{acre}$$

for net property tax burden of $103.62/acre, nearly three times the Federal income tax burden.

This simple illustration ignores many complexities of forecasting and detail, but the values used are realistic and the message is clear: Property taxes rank high, perhaps highest, for most owners, among the costs of the timber growing enterprise.

Effects of Transfer Taxes

Transfer taxes can seriously disrupt long-rang timber management plans. The most common reason for this effect is lack of cash with which to pay transfer taxes on the property. Often, the only way to raise this cash is to liquidate the assets themselves, which can mean premature timber harvest or forced sale of timber (or both land and timber) at bargain prices.

A variety of complex trust arrangements are possible which can lessen or postpone the impact of death taxes on a family's timberlands. But, perhaps the most straightforward approach to the problem of enabling descendents to continue management of a forest property is the lifetime gift. Conway (1974) has noted four advantages, under Federal tax law, of gifts made during the lifetime of the donor: 1) Federal gift tax rates are only 75% of estate tax rates. 2) Property can be shifted from under the burden of the highest tax rate to which an estate will be liable to the lowest gift tax rate possible in view of any previous gifts the donor may have made. 3) The amount of gift taxes paid is not subject to the estate tax. 4) Whereas the estate tax is imposed on the size of the estate, which *includes* the amount of estate taxes payable, the gift tax is levied only on the amount of the gift.

State death taxes are so similar to and, in some cases, so closely related to Federal estate taxes that management planning can be confined largely to the provisions of the latter.

TAX TRENDS

Future trends in income, property, and transfe taxation are no more certain than other futures, but it is well to monitor proposals for change and to judge the probable impacts on long-range decisions The two most volatile topics at the moment appear to be the Federal income tax and Federal transfer taxes

Federal Income Taxes

Capital gains treatment of timber has been criticized regularly over the years. Recent reforms of the percentage depletion allowance for oil wells, a monumental tax loophole with which timber *cost* depletion has often been confused, may relieve pressure from that quarter. But, the Congressional Budget Act of 1974 requires an annual summary of "tax expenditures", defined as revenue losses due to provisions of Federal tax law which allow some sort of preferential exclusion or tax rate (Sunley, 1976). The capital gains treatment of timber is a tax expenditure, so is ensured of annual review, but I can see no logical argument for denying or modifying preferential treatment of timber as a capital asset unless all other capital assets are so treated. It might be reasonable, though, to expect a lengthening of the holding period for a long-term capital gain from six months to several years. Such a change would effectively deny capital gains treatment to most stumpage buyers, but should have little if any effect on intensive management.

Investment credit was first allowed under the Revenue Act of 1962. It was suspended, for property costing over $20,000, from October 10, 1966 through March 9, 1967, and was terminated altogether by the Tax Reform Act of 1969. The Revenue Act of 1971 restored a 7% credit for eligible property and the rate was increased to 10%, for most cases, by the Tax Reduction Act of 1975. Presumably, rates will return to the 1971 level if the reduction provisions are not continued.

Federal Transfer Taxes

The last thorough reform of Federal transfer tax law was in 1942. There has been much talk of change but little action since then (Conway, 1974). The Administration's Tax Reform Bill of 1973 emphasized three broad concerns, which are likely to continue: 1) maintenance of existing revenues from these taxes; 2) gradual, rather than abrupt changes, to protect those who have planned their estates under existing law; 3) maintenance of advantages which encourage support of charities. There have been serious proposals to revise the rate structures, eliminate the double benefit afforded by the separate $30,000 and $60,000 exemptions of the gift and estate tax laws, respectively, and to impose a capital gains tax at death on the fair market value of a property, less its cost basis. Perhaps the extreme example of attempts to block transfers of wealth from one generation to another was George McGovern's call a few years ago for a 100% estate tax.

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EFFECTS OF INCENTIVES PROGRAMS

by

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Abstract

Incentives have played an important role in forestry accomplishments on private forest lands. Direct cost-share assistance programs, such as the Forestry Incentives Program, stimulate additional accomplishments in greater proportion than their actual inputs. Two States currently operate their own "incentives" programs. In addition, the Pacific Northwest Regional Commission has provided funding to supplement Federal cost-sharing in Washington, Oregon, and Idaho.

In 1974 the Forestry Incentives Program treated 257,000 acres on 15,800 separate tracts of forest land. Tract size averaged better than 15 acres with more than three-fourths of the tracts treated exceeding a production capacity of 85 cubic feet/acre/year. Treatment costs are similar to those experienced on industrial and Federal lands.

It is a pleasure to be back in Maine again with old friends. I spent 4 days here in early May visiting some of the woodlands in which we have invested cost-share funds. You currently have here in southern and western Maine a market situation second to none. This is ideal, for it enables a forester to look at all possibilities of getting stand treatments accomplished. But I'm getting ahead of myself. Let's back up a little and get our perspective set on incentives programs in general--what they are--where they came from--how they operate.

Many of our direct "incentives" programs have been in operation for several decades. Programs such as cooperative fire protection and nursery production have been on the scene for more than 50 years. The Agricultural Conservation Program (ACP), under one or more names, has been around since 1936. Forest management assistance, which was formalized by the CFM Act of 1950, really had its beginning in the Norris-Doxey Act of 1937. And the latest, the Forestry Incentives Program (FIP), has been in operation for only a little more than 2 years.

During these years we have come to accept these programs as being basic to the accomplishment of forestry measures on ce tain private lands. Events over the past few years indicate this attitude may be changing fast. The rescission (and defe rals) requested on FIP and ACP in the past two congressional sessions and the proposed phasing out of the Clarke-McNary Section 2 (CM-2) fire protection funding, along with similar actions in other resource programs, give ample evidence that he Federal role on private lands is being seriously reviewed, ar in some areas, questioned as to its propriety or effectivenes, The President's transmittal letter that accompanied the RPA documents to Congress states this in clear and unequivocal te ns

Despite the unprecedented demand for Forestry Incentives Program funds and its accomplishments of the past 2 years in getting tree planting and TSI done on nonindustrial private forest lands, certain groups and individuals insist that dire Federal incentives have no place on private lands. They beli ve that the unhampered operation of a free market will take care of the demand or need for forestry investments on these lands.

Are such "direct" incentives really necessary? This is ot an easy question to answer. Some studies have shown (Yoho an James, 1958) that landowners indicate they would have carried ou forestry measures without such assistance. Another recent st y (Gregersen, 1975) shows that 41 percent of landowners respond ng to a questionnaire indicated they could have earned an altern tive rate of return without the cost-share assistance. It is difficult to know what a person would have done in a situatio he didn't have to face. We do know, however, that when cost-share assistance programs are terminated, such as was the cas in 1972, TSI activities on nonindustrial private lands drop drastically. Tree planting activities do not react this quic y Records show that when REAP was terminated by President Nixon n December 1972, planting and seeding activities did diminish-- t only by about 35,000 acres, about 12 percent below the previo year's level. Tree planting activities require pre-planning, matched with the availability of nursery stock, and depending n degree on site preparation. Thus, when cranked-up, tree planting tends to be a more stable operation--not reacting as quickly to short-term fluctuations as is the case with TSI.

It is interesting to note that on the nonindustrial private forest lands tree planting accomplishments reached a peak in 1959 (1,465,000 acres) during the Soil Bank days. There was ample funding from Federal sources and tree nurseries reacted with greatly increased production. As this funding dropped o , an even deeper drop in tree planting activities occurred. By 1962, Federal funding for this purpose had declined to about $4 million, and tree planting dropped to less than 600,000 ac s

TSI accomplishments peaked in 1958 and declined until 1965, these levels being wholly dependent upon Federal cost-share assistance. So there seems to be little doubt that the presence of Federal incentives payments acts as a catalyst, and in the case of tree planting in a greater proportion than its total amount. The discouraging aspect is that levels of accomplishment for both planting and TSI on these ownerships are woefully below the levels needed--probably even below replacement of current losses. The size of the reforestation and stand improvement job is so immense--and the objectives of owners and constraints facing them are so varied--that a wide variety of approaches (including forest tax relief, loans, insurance, and many other "indirect" incentives) will be needed if these lands are to provide their commensurate share of forest products and services.

Let's take a quick look at some of the direct incentives programs in operation now.

Two States operate their own "incentives" programs

Virginia's RT (Reforestation of Timberlands, 1971) program is restricted to the planting of pine on private lands, both industrial and nonindustrial. It is financed by a levy on the forest products industries. Annual and/or up-to-3-year contracts may be approved. The 1975 planting level under this program exceeded 17,000 acres on 390 tracts of land.

Mississippi's FRDA (Forest Resources Development Act, 1974) program offers both planting and TSI practices on nonindustrial private, State, and municipal lands. It is financed by a special fund which includes the privelege tax on timber and timber products and any monies appropriated therefor. Other provisions closely follow the Federal FIP guidelines, including both site preparation/planting and TSI practices.

Using a somewhat different approach, the Pacific Northwest Regional Commission has granted funds to their three States in the Pacific Northwest (Idaho, Oregon, Washington) to supplement the regular FIP program in that region. The Regional Commission granted $200,000 to each State to provide incentives to landowners holding larger tracts than those eligible under FIP and also to assist small forest industries. To date Oregon and Washington have gotten their respective (OFIP and TIP) programs underway, but Idaho is not yet operative.

Perhaps the best known "incentives" program is the ACP (Agricultural Conservation Program). Originally authorized in 1936 as a part of the Soil Conservation and Domestic Allotment Act of 1936, its original intent was to prevent erosion and stabilize rural economies. ACP has been (under a variety of acronyms) offering cost-share assistance to agricultural producers for a great number of conservation practices. Two forestry practices have been offered along with other county special practices to solve local problems unique to that area. Representative Jamie Whitten, Chairman of the Agriculture Subcommittee, House Appropriations Committee, has testified that more than 7 billion trees have been planted under the ACP since its inception.

In the recent past (1965-1971) funds for forestry practices under the ACP averaged slightly over $4 million each year on about 380-390 thousand acres. Thirty to 35 thousand landowners were assisted annually by this program. ACP has been unable to forcefully address the backlog in forestry treatments because it is primarily structured for agricultural purposes. In any given year the total amount of funds obligated for forestry purposes rarely exceeded 4 percent of the total national ACP allocation. Usually forestry practices utilized 2 to 3 percent of the budget. This was one of the reasons that a separate cost-sharing program designed specifically to accelerate timber production was necessary.

So now let's take a look at FIP, the newest of the direct incentives programs--what it is supposed to accomplish and how well it is doing to date.

The wording of testimony and the language of the Act make quite clear that the purpose of FIP is timber production. And President Nixon directed that FIP be carried out in a "cost-effective" manner in his message accompanying the legislation (P.L. 93-86). Funds to the States have been allocated on the basis of opportunities for timber production on nonindustrial private tracts less than 500 acres in size. In its first year of operation (1974) Congress did not appropriate any funds for FIP, so ASCS set aside $9 million from their regular RECP funds to operate the program. This meant that FIP operated under regular program rules that year. With this constraint, it was difficult to optimize timber production goals.

The 1975 FIP funds were truly "incentives" dollars, a hard cash appropriation, "no-year" funds available until expended and with a maximum per person payment of $10,000/year (as opposed to only $2,500 maximum under regular program). Fifteen million dollars were made available in May of 1975, and by December of that year these funds were obligated and a backlog of requests in excess of $8 million existed. The response to FIP has simply been overwhelming.

The Administration requested a rescission of the 1976 FIP unds; Congress refused this proposal; and these monies ($15 illion) were just distributed to the field in late March. An dditional $3.75 million to cover the transition quarter has een made available since July 1 of this year. The current ituation on funding is that the Administration did not include unds for FIP in its 1977 budget. The House Subcommittee on griculture has just inserted $15 million in their budget at he time of writing. Now on July 22, I am able to give you an pdate on its status.

Now let's take a look at what FIP has accomplished along ith some indicators of cost-effective performance.

THE 1974 FORESTRY INCENTIVES PROGRAM

reated		257,000 acres
including	(36%)	100,000 acres of TSI and
	(64%)	157,000 acres of tree planting;
more than		15,800 separate forest tracts
owned by		13,500 landowners

were involved.

Total Federal funds = $ 8.266 million

Landowner Expend. = $ 3.100 million
TOTAL $11.366 million

onsidering the four major indexes of cost-effectiveness, 1974 IP performed well in all.

ract Size: Seventy-four percent of all the tracts treated were greater than 15 acres in size. In the South, one-third of all treatments were on tracts larger than 51 acres.

ite Productivity: More than 75 percent of all the acres treated under 1974 FIP were on sites capable of producing at least 85 cubic feet/acre/year (1 cord/acre/year). Sixteen percent of sites treated were capable of growing in excess of 121 cubic feet/acre/year. I'm happy to report that the State of Maine topped the Northeastern States in this category.

inds of Treatments Applied: Well-recognized practices were applied on the majority of acres treated with 1974 FIP.

The following practices, when applied with reasonable costs are recognized as yielding favorable financial returns:

Site preparation and planting of southern pines.

Site preparation and planting of red, white, and jack pines.

Precommercial thinning and release in southern pines.

Precommercial thinning and release in maple/beech/birch.

Precommercial thinning and release in Douglas-fir, and ponderosa pine.

These five practices comprised 75 percent of the acres treated in 1974 FIP. There is little doubt that the majority of forest practices utilized in the 1974 FIP were capable of providing good financial returns when properly applied on productive sites.

Treatment Costs: The cost of applying these practices were highly variable between individual States and regions. The national average total cost for site preparation and tree planting was $52/acre, composed of a

$37 Federal cost-share, and a

$15 landowner contribution.

The national average total cost for all TSI measures was

$30/acre, composed of a

$22 Federal cost-share and an

$ 8 landowner contribution.

Costs for a combination of site preparation and planting were lowest here in the Northeast and in the Lake States. Lowest costs for TSI were found in the States of Georgia, Missouri, and Indiana and averaged from $19 to $21 per acre.

The average FIP treatment costs are similar to those experienced on industrial and Federal lands. We believe that our costs of installing forestry practices on nonindustrial private forest lands under this program to date are reasonable and prudent.

Of course, a comparison of true cost-effectiveness must
nclude all or most of the indexes above. Our analysis to date
hows the FIP to have contributed to the goal of cost-effective
imber production.

In closing, I'd like to read you a letter which may typify
ome smaller private forest landowners' attitudes on incentives
nd the part they play in profitably growing timber. This
etter certainly provides a perspective that foresters and
conomists often overlook.

ear President Ford:

I hope you and your family have a very good and successful
976, especially in November. I am writing directly to you
ince I am sure you are not aware of certain aspects of the
orestry Incentives Program for 1976.

In Virginia I am a tree farmer, raising loblolly pine,
oplar, and native hardwoods on about 300 acres. I bought this
and in 1965 for $30 per acre. It is now worth about $600-800
er acre. It costs me about $50 per acre to plant trees and
nother $50 per acre to kill the undergrowth two years later.
t may cost me another $25 per acre to kill scrub trees to pre-
are site for planting.

This means I may have to put in, currently, $125 per acre
or an established acre. I plant 10-20 acres each year. Thus,
t will cost me eventually $1,250 to $2,400 a year to plant.

I must have this money tied up for 18-25 years in growth
ill the seedlings become pulpwood. In 18-25 years at 7-½ per-
ent (which I get at a finance company) the $1,200-2,400 is
orth from $4,800-9,600. I have been investing that kind of
oney since 1965, some years less, but averaging that.

Now--I have gotten at least half that money from State and/
r Federal programs such as FIP, REAP, and I forget the initials
f the earlier program.

I have known for five years it is a bad investment to
ontinue reforestation programs--even with Federal help. But,
s FIP is called--INCENTIVE is the word. Like any other human
nterprise, a little encouragement has caused me to shut my
yes to the fact my farm could be sold for about $180,000-
240,000. If invested, my income would be about $15,000 per

year--starting NOW, not 18-25 years from now. I want to grow trees, and I want to keep my land in my future and my children's future and in my country's service. Please consider that there are thousands more like me.

Sincerely,

It has been said that there are only two kinds of fools in the world. One says, "It is old and therefore good." The other says, "It is new and therefore better." If forestry on private ownerships is ever to reach its considerable potential, we are simply going to have to take the best from the past and combine these with even better new techniques to create sufficient incentives for the private forest landowner.

The keynote of progress, we should remember, is not merely doing away with what is bad. It involves replacing the best with something even better. We need to keep this in mind as we strive to create a climate in which private forestry can prosper.

POSSIBLE LEGISLATIVE CONSTRAINTS TO INTENSIVE SILVICULTURAL PRACTICES IN NORTHERN FOREST TYPES

by Brendan J. Whittaker, Chief, Information &
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Abstract

The question of legal constraints to forest practice is currently active again. Two sources of restriction are the historic concern for timber supply and related amenities, and the mandates of the Federal Water Pollution Law. Legislators by and large, both State and Federal, realize the need of the nation for timber and will give due weight to the data presented to them by professional foresters. Foresters, on their part, have the obligation to become even more involved in the legislative process and to present the basics of sustained yield forestry in a clear and understandable manner.

These comments on legal restraints to intensive silviculture come from the admittedly subjective viewpoint of one who, though he has a forestry background, now works in a state-level multi-discipline environmental agency in Northern New England. In this position I do follow quite closely our own state legislature but, on the other hand, can only, from general reading or other information sources, learn what is happening in the forest regulatory field over a wider area. I would ask, therefore, that you take the following comments and balance them against the situation in your own state or region.

First, although it is not in my assigned topic, let's recall that legislation or administrative regulation is not necessarily a detriment or restraint to forestry. They can be a benefit! A serious situation in Vermont, for example, is forest land taxation, the all-too-familiar story of land taxes far in excess of the forestry or agricultural capacity of the land to produce a cash return. A good tax law revision in this instance would aid in removing a restraint to intensive silviculture.

An even more intriguing example in Vermont now comes at a time when we hear that interest in environmental legislation has ebbed. However, the latest information concerning "Act 250", our basic land development law, without going into a great amount of detail, is that due to the legislation as now written, there has been a proliferation of land subdivisions of just ten acres or slightly over - the minimum subdivision which escapes Act 250 jurisdiction - with obvious adverse effects on the practice of forestry. It is more difficult for logging operators or foresters to deal with a multiplicity of small ownerships of ten acres each laid out with no regard to natural features such as ridge tops or stream valleys.

The point to be made is that instead of cries for the dismantling of Act 250, what is heard are pleas for some innovative and creative strengthening of the law to remove the small or irregular lot detriment to forest management, while at the same time preserving, as far as possible, the free market concept in land sales. What the outcome will be is unclear at this time, but some very responsible people, including the Forests & Parks Commissioner, are seeking through law and regulation to enhance, rather than restrict, the practice of silviculture.

Now, it seems to me that possible legislative or regulatory restraints to intensive silviculture can be reasonably expected, if they come at all, from either or both of two governmental levels, state and federal, since, as most realize, New England has only a skeletal county government compared with much of the United States; and any prospective town laws or regulations on timber cutting would obviously have only an extremely local effect. As urbanization progresses, however, such local restrictions can become quite severe on woodland owners. For example, although not aware of them personally, I am told that local ordinances against tree cutting are extremely severe in such New Jersey townships as Hampton and Parsippany-Troy Hills.

Potential areas of regulation can reasonably expected to be:

1) Measures designed especially to fulfill the mandates of what has been recently described as "one of the most complex pieces of legislation ever passed by the United States Congress",[1] PL 92-500, the Federal Water Pollution Control Act.

2) Measures intended to maintain levels of forest productivity, a historic American concern, now widely expanded, however, to not only to the nation's timber supply, but related resources and amenities such as scenic values, clean water, and recreation areas. This latter would include the sometimes emotion-laden term "wilderness areas".

3) Combinations of these areas in such matters as pesticide and silvicide regulation, road building and other forest-related construction, even perhaps controlled burning if this should come into wider use in the northern forest. These latter concerns not only raise the wider interest of foresters and environmentalists as they always have, but now also will be examined in the light of PL 92-500 to see if their use will affect water quality in the forest.

* * *

To look at the first area, the Federal Water Quality Act, the Section numbers of 92-500 - "106", "201", "402", "404", "303(e)", and "208" - have become stock phrases among environmentally aware people at all levels, and if the numbers at least are unknown or a mystery to the general public, the effects of these Sections of the Law are beginning to reach to the remotest corners, hills, and valleys and river bottoms of all 50 states.

It's a massive program to say the least. 201 construction grants to build sewage treatment plants and related facilities now total billions of dollars annually. 303 River Basin Plans have had hearings in all parts of the region which, though generally sparsely attended, are sources of huge amount of detail for future water quality planning in the immediate area. The 404 section, the so-called Dredge and Fill, is of immediate interest to forestry since it, as the result of a federal court decision, requires the U.S. Army Corps of Engineers to extend jurisdiction on dredge activities to the most upland stream areas and their attendant wetlands. We are now, as of July 1 of this year, in phase 2 of Section 404 implementation which extends Corps jurisdiction to all major rivers. Next year, July 1, will complete implementation of Corps jurisdiction right up into the headwaters. As of now, it is determined that permits will be needed for several activities commonly used in forestry such as stream crossings. In order to, as one water engineer in Vermont puts it, "soften the blow", the Corps is proposing general permits to be issued to a state to cover the more routine activities; but apparently negotiations on the details between the states and the Corps are not progressing too well at this point. To compound our own situation in Vermont, our State is split down the middle by two Corps jurisdictions and conceivably a timber operator somewhere on the height of land of the Champlain and Connecticut watersheds could find himself applying to both Albany and Waltham for permits for the same operation. Vermont, obviously, is currently trying to rectify this situation.

Several changes by amendment are now in process in Washington on the whole Water Quality Act. A proposal on this 404 section, however, to redefine Corps jurisdiction on dredge and fill to truly navigable waters, the so-called Breaux amendment, failed in June. Our own position in Vermont is that the states keep jurisdiction over most waters, with the Corps retaining jurisdiction over the traditional navigable waters, but we do realize the need for wetlands legislation of our own, an area which many feel is inadequately covered by law at this time. A possible compromise could be a requirement that all states enact suitable wetlands legislation and then be "signed off" by the Federal Government to run their own dredge and fill programs. We understand a major concern about this among environmentally oriented Congressmen is that approximately half of the states have no wetlands legislation at all.

The last section of PL 92-500 I will mention is 208. This is a broadly designed planning action designed to involve citizens at a very basic level in planning for future water quality needs where complex problems exist. 208 has been described as a form of land use planning, with all of the positive and negative connotations this term brings, since it is obvious that man's treatment of the land affects water quality. Vermont is just beginning its involvement with 208. We are being cautious. A state level committee headed by the Secretary of my Agency has been established with participants from all sectors with an emphasis on participation by the agricultural community. We plan to do the groundwork on 208 through the 13 Regional Planning areas in Vermont.

I would urge you to check carefully the 208 setup in your own state if you have not done so already, or if you are not participating at this time. Forestry needs to be represented on this planning level which will be recommending basic land use decisions affecting us for years to come. I do know that eastern Massachusetts, particularly, has 208 planning areas and staffs who are further along than we in northern New England, and though, obviously, that is a highly urbanized area, a visit to them if you are in the vicinity will show somewhat where we might be as 208 progresses.

208 is under consideration for change with some amendments in Washington at this time. One proposal receiving serious attention is to add air pollution and solid waste to the 208-type model. The result would be a complete waste planning effort and the ramifications for land use planning therefore even broader.

As a late update to the whole question of amendments to PL 92-500, our water resources people tell us that the most appropriate forum toward which we may address our comments is now Senate Bill S-2710 which has passed the House as HR 9560 and is now back in the Senate to resolve differences.

* * *

The second major area of regulation is that intended to maintain levels of forest productivity. This is a historic concern; it's been pointed out by others that debate on the timber supply issue has been strong in at least three previous periods in our history: 1910, 1923-1924, and 1938-1952.[2] At the present time, of course, the added concerns of many interest groups accompany the timber shortage worries. I will not go into great detail on forest practice laws but will make some general observations from our standpoint in Vermont. First, something is definitely "in the wind" again regarding the regulation of cutting on both government and private lands; it's an issue that is very active. To expand on this a little, we have the very concrete and highly visible congressional action in Washington rewriting the basic Forest Service Organic Act. As most of you undoubtedly know, this action grew out of a federal court ruling on clearcutting in West Virginia on Forest Service land, a ruling now known as the Monongahela decision. There is also in effect now a new federal law entitled the Forest and Range Land Renewable Resources Planning Act (RPA), requiring an ongoing long-range assessment, planning and program on the management primarily of federal lands. The status of state and privately owned land resources will, however, also increasingly figure in Federal land program decisions.

Already these two major Federal activities, Forest Service Organic Act Revision and RPA, are becoming interrelated in that the major Organic Act rewrite, S-3091, the "Humphrey Bill", makes reference to, and ties in with, the RPA already passed. Now we, at the state level, could sit back, and say "that pertains only to federal lands". I don't think we should be misled, however. Any forest-related legislation as comprehensive as the two Federal actions just mentioned are bound to have "spin-off" effects on state and private forestry. Indeed, I an told that the states have been asked to assume responsibility for a Resources Planning Act type of effort on state and private lands. Even if that does not happen, a major debate with press and television coverage of, for example, Forest Service clearcutting practices, would bring that issue to the fore on state and private forest levels, also.

(Permit an anecdote here: Until now, tree length clearcutting and chip harvesting in Vermont has been confined to a relatively small and remote area in the northeastern section. Already, however, we have received at my Agency some heated comments and questions from travellers into the area such as snowmobilers and hunters. It is my contention that if and when the clear-cut-chip harvest operations move down state in view of Interstates 91 and 89, the public outcry for regulation for cutting, even on private land, will be very large.)

At least up to now, forest practice regulation has been at the state level with a measure of largely voluntary state-federal cooperation. That this is likely to continue is indicated in an important policy speech given by John R. McGuire, Chief of the U.S. Forest Service on February 10, 1975, to a joint Forest Service - EPA sponsored meeting on state forest practices legislation in Washington, D.C. McGuire said, in part, "Forest practice regulation, if necessary for whatever purpose, is not a federal function. Any such legislation should be developed, implemented, and administered within the established pattern of federal-state-private cooperation in forestry matters".[3]

Perry Hagenstein, Executive Director of the New England Natural Resources Center in Boston, has prepared a paper on forest practice legislation in New England.[4] This is an excellent source of information regarding forest regulation on our own area. A conclusion Hagenstein drew was that regulations are most effective when designed to deal with specific problems fairly narrowly defined. On the other hand, he felt that broadly applicable laws on cutting when enacted in the past, have often simply not been enforced. Hagenstein wrote his paper to relate forest regulation to the water quality problem mentioned above, but it would seem his conclusions would apply to the timber supply and aesthetic concerns also.

I would like to step aside now for a moment in conclusion and,notwithstanding all my biases as a forester and professional environmentalist, try to put myself in the place of a Vermont legislator as he or she might look at the question of regulation of cutting on private lands in my state, if the matter comes up for legislation. Leaving the narrower question of water quality aside, I believe, as a legislator, I would be open toward leaving forest practices in private and professional hands with, however, some important qualifications. The most important of these is that, as a legislator or even private citizen, I would want to hear from professional foresters about the concept of sustained yield, defined something like this: "repeated crops of timber removed at regular defined intervals, into the future as far as man will control it; with no degradation of the soil or water base and the maintenance of a healthy, productive forest". I would like to hear that from foresters, and I would like them to delineate the areas on which they intend to do it.

Most legislators in Vermont are beginning to realize that wood is the only large-scale renewable resource we have. If, for example, as seems likely in out state, we move into generation of electrical power with wood fuel and/or if another large paper mill is located in the upper Connecticut Valley, the wood resources of Vermont would be even more crucial to our economy and well-being. Dialogue and debates with recreationists, environmental groups, and others, some of whom might wish to restrict cutting, will continue, but I believe that legislators will give due weight to reasoned, professional advice from foresters, if the lawmakers can believe that the timber business is here to stay on a sustained yield basis.

(A superb example of the sort of intelligent lucid professional testimony that would be most helpful to me were I a legislator was that of the President of the Society of American Foresters, R. Keith Arnold, before the Forests Sub-Committee on Agriculture, U.S. House of Representatives, on March 24, 1976. Arnold was testifying on one of the proposed rewrites of the U.S. Forest Service Organic Act. This testimony may be found verbatim in the May 1976 Journal of Forestry.)

There will be debates and problems in the future in Vermont on forest practice regulation. I still think, however, if we do our own work, know what we are about, and are able to communicate it effectively, we will have our just hearing in the legislative process. In our system of government, we really cannot ask for more.

The major conclusion to be draws from all of this is one that has been repeated many times among professional foresters, but it now assumes a new urgency. Foresters must assume a more active role in guiding forest practice regulation. We will have to become involved in the political process, in information and education programs, in dealing face-to-face with recreation special interest groups, and in public relations efforts. And, we must make sure we do our own homework, so that we present our case for intensive silviculture on the soundest professional base.

In this light, I will end on a personal note. I have a son who is planning to enter forestry school next fall. There are two things I intend to share with him as he enters his professional studies. One is a paper by Benjamin A. Roach of the U.S. Forest Service, written for the Applied Forestry Research Institute at Syracuse. It is entitled, Selection Cutting and Group Selection. I have read it and marked it up at least three times. Having been out of forestry school for twenty years this summer, I had really forgotten a lot about the absolute basics of our profession: terms such as "regeneration method", "silvicultural system", "regulatory system", "sustained yield", "even age and uneven age management". Can you define each of the above in clear lucid terms to a layman? Roach can and does. He is well worth reading over and over again.[4]

I feel if I explained Roach's paper to my son and also gave him the rudiments of the use of basal area and, if he can walk out on our own 70-acre woodlot and explain these terms satisfactorily to a non-professional visitor, he will have the basics of what he, as a forester, will deal with all his professional career, no matter what sophisticated courses beyond that he may receive at a university.

Footnotes

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[1] "Water Pollution Control and Forestry" - George W. Brown, Raymond M. Rice, and Robert B. Thomas. Journal of Forestry, Vol. 74, No. 6, June 1976. p. 344.

[2] Remarks by John R. McGuire, Chief, U.S. Forest Service, Washington, D.C., February 10, 1975

[3] ibid.

[4] "Selection Cutting and Group Selection" - A paper by Benjamin A. Roach, Research Forester, Northeastern Forest Experiment Station. The paper is available from the Applied Forestry Research Institute, State University of New York, College of Environmental Science and Forestry, Syracuse, New York 13210

TECHNICAL ASSISTANCE FOR INTENSIVE CULTURE OF NORTHERN FOREST TYPES

BY Timothy G. OKeefe, Extension Forester, University of Maine, Orono, Maine.

Origin & Types of Technical Assistance (TA):

During this Bicentennial celebration, it is interesting to note that in America TA programs in forestry have evolved from both a formal and an informal foundation. European foresters, attempting to motivate many small forest landowners to practice more intensive forest management, have learned that incentive and educational TA programs are far more effective than programs of regulation and control. Throughout American history there are many examples of "informal" arrangements that were in fact a form of technical assistance. In colonial America, the old custom of community barn raising is a good example of an informal kind of technical assistance. The Cooperstown forestry cooperative might be considered as a kind of formal program of TA. Another good example of a formal TA program is the educational forestry programs operated within the framework of the Cooperative Extension Service.

Today, there are many other types of TA programs in the forestry field. Most of these assistance programs can be classified as field or educational efforts. The field type of TA program is basically applied assistance. Most of the service forestry--both industrial and State C.F.M.--programs are operated as direct field types of TA. In many areas, private consulting foresters also offer a field type of TA on a fee basis. Attached to many State forestry organizations is a forest products utilization specialist who often functions in a field capacity by providing market information. Educational types of TA programs include forest Extension activities from the Land Grant college, as well as the organized I & E programs from state and federal forestry organizations. Industrial forestry organizations are also active in the educational type of TA program; AFI, APA, and in Maine the Forest Products Council and P-IIO are good examples of effective educational TA programs.

Technical assistance in forestry is also provided within a mixed framework of field/education programs by a number of unique organizations. At the federal level the State and Private Forestry Division of the U.S. Forest Service is actively engaged in a wide variety of TA (e.g. sawmill improvement programs). Specialized research labs, such as the Madison Forest Products Lab, often carry out different types of TA. On the private level, many groups such as Christmas tree growers, maple products producers, and small forest landowners associations carry out active educational programs, as well as field assistance programs such as "cooperative" marketing. The Tree Farm program is an industrial TA program operated in a mixed framework.

Who are the recipients of all this TA action? Indirectly, any forest manager dealing with any size and any type of forest land is part of the TA client group. More specifically much of the TA work is directed to:

1. general citizen groups, including youth
2. small forest landowners
3. small forest products manufacturers
4. small producers of non-timber forest products.

Of course, many individuals may be a member of more than one client group. And the characteristics of these client groups are most variable.

Objectives and Success of TA:

Most field type TA programs are designed to supply some rather specific service to the client group. For example, service forestry programs usually aim to provide small forest landowners with a limited range of woodlot services, such as tree marking and TSI recommendations. The field type TA programs are usually structured so that, in general, most of the rather specific goals of the program can be clearly evaluated. In 1975, the USDA Forest Service published an evaluation of the CFM program. This evaluation reached a number of conclusions, such as:

1. a serious lack of manpower and funding prevents full return on the CFM program.
2. financial incentives for management are important.
3. information aspects of CFM must be improved.

The educational type of TA program is usually designed to meet a wide range of more general goals. For this reason, it is usually more difficult to determine the degree of success with an educational TA program. Such educational TA programs often attempt to provide some client group with correct forestry information that will result in a change of attitude or in some more specific action. When some specific action, such as a request for management assistance, is a primary goal of the program it is usually easier to evaluate. However, the success of those programs aimed more directly at a change in client attitude are much more difficult to assess.

In recent years, the American Forest Institute contracted with a professional survey organization to evaluate the impact of forestry education programs on the general public. These evaluations show some interesting results. Generally, there seems to be increased awareness and concern about forestry in all segments of the general public. Forest industry seems to have maintained a generally creditable image with the public. Unfortunately, on the negative side, there is still a high degree of public misunderstanding about forestry and forest practice. Based on the results of these surveys, there is yet a great deal of educational TA to be completed.

Indirectly, there are certainly other ways to evaluate the success of the forestry TA program. For example, public attitude reflected in the ballot on a critical forestry issue, may be one indirect measure of the effectiveness of the educational TA program. With regard to field type TA programs, it might be possible to evaluate the program in terms of improved operation methods or improved quality of growing stock. Numbers of program participants, or even the percentage results of a survey can furnish part of the total success picture when forestry TA programs are evaluated.

Applications and Limitations:

Programs of TA in forestry must represent an important factor that will determine effective implementation of intensive cultural practices. Basic to implementation of any program of intensive cultural practices is public understanding and acceptance. Therefore, educational types of TA activities are essential if intensive forestry programs are to be successfully implemented. In fact, it will probably be necessary to increase the level of educational TA in proportion to the degree of complexity associated with proposed programs of intensive forestry practices.

For the small forest landowner (who represents about 59% of the nations forest landowners) in addition to education TA, the field TA program will be essential for successful implementation of intensive forest practices. Small landowners must first be motivated (educational TA) and then must be shown how (field TA) to accomplish the recommended intensive cultural practices on the ground.

Expanded TA programs designed to promote intensive forest practices can be successful only to the degree that the major obstacles can be overcome. In connection with large scale (public and industrial private forestry) programs of intensive forestry, the major constraint is probably the large number of very diverse interest groups. A better understanding of forest landowner's goals will be necessary in order to determine the correct procedures for motivating the landowner to practice more intensive forest management. A solution to this problem possibly lies in greater use of the mass media for communication; more active use of established programs in public schools, adult education, and cooperative Extension. Another major TA problem connected with the small forest landowner lies in active contact with the very large number of landowners. In Maine alone, it is estimated that there are 100,000 small forest landowners. Thus, a field TA program that could reach each of these small landowners on a continual basis must require a very high input of manpower and money, above present levels.

In summary, the degree of success from most programs of intensive forest practice will depend upon the degree to which effective TA programs are developed and implemented. The basic technical information to implement intensive forest practices is generally available now. The most significant limitation for any program of intensive forestry is the component of effective TA - both educational and field programs.

CLOSING COMMENTS

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The papers presented during the two and one half days of this symposium have provided all of us with a deeper understanding of the present knowledge on intensive management but they have also left us with many questions about the future. There is first an overwhelming feeling that we are doing too little about our problems and perhaps we are too late to meet potential requirements. We should have all of our productive northern forest types under intensive multiple use management but how soon will this happen?

Why should we mention a note of pessimism when we have been shown that intensive management can be accomplished? Chief McGuire said and I quote from his paper - "There is no doubt that private lands--particularly small, non-industrial holdings - are the key to meeting future demands for forest resources. And please remember that while this conference deals mainly with wood supplies, the demands for other forest uses are increasing just as rapidly--in some cases, more rapidly". Can we get these private lands under intensive management soon enough to meet our future needs? Must we depend upon strict regulation to meet the requirements? Will rising prices and rising demands result in a wave of exploitation? Hopefully we can establish good management practices on all lands without excessive regulation before the pressure for more fiber destroys the opportunity.

Robert Phelps pointed out our needs and gave us our charge. He pointed out how we might get a little more production by improving efficiency of utilization and we could gain some addition to meet future needs through imports. But, in a competitive world our future needs for additional wood must come mainly through management.

We must set our goals and go after them without delay. Are we ready as a general public to set realistic goals that everyone understands? We have discussed many ideas related to these questions and we have shown clearly that we have knowledge that is not being utilized for various reasons. Some general impressions that I have developed from these discussions are as follows:

(1) We have much knowledge about intensive management but we are not utilizing that information on a large scale.

(2) The northern forest types may be managed inten-

sively in a variety of ways depending upon a host of varying conditions which may be biological, economic or social.

(3) Research must continue at a rapid pace to develop further methods for culture of the northern forests.

(4) There is a critical need for the development of an understanding in the public sector about the need for and methods of intensive management.

(5) The managers of forested tracts have a difficult adjustment to make in changing from present methods to more intensive procedures requiring closer supervision of on the ground activities.

(6) Education must concentrate on preparing more foresters with an interest in close attention to detail and a desire to stay in close contact with the forest. Intensive management requires more foresters with specializations but proportionally will require many more with a desire to work in the woods caring for relatively small acreages of forests.

(7) Management of northern forest types has been crude and rough. Intensive management requires the development of the attitudes of artists who look on work as a creative production and an exciting experience. The change requires a real commitment all along the line.

(8) Very little will be done unless the economic climate is adjusted considerably. The forest is the resource on which our large industry must subsist; it is the playground for millions of people; it is the home for many wild plants and animals; it has a profound influence on our physical lives. Yet, the forest receives the least portion of support possible. Timber buyers pay the least stumpage possible, Recreationists expect to use the forest for nothing, Game managers treat animals as a by-product and hunters pay very little of their fees toward management of the habitat. There are hopeful signs but we can only hope that the changes to a real recognition of forest values comes soon.

This symposium has provided all of us with a status report on management of northern forests. It has provided ideas for the future. Dr. Blum and his very fine committee should be complimented for developing a much needed review. It is up to all of us to carry out the program in the future.

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Northeastern Forest Experiment Station.
1977. **Proceedings of the symposium on intensive culture of northern forest types.** Northeast. For. Exp. Stn., Upper Darby, Pa. 356 p., illus. (USDA For. Serv. Gen. Tech. Rep. NE-29)

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Headquarters of the Northeastern Forest Experiment Station are in Upper Darby, Pa. Field laboratories and research units are maintained at:

- Amherst, Massachusetts, in cooperation with the University of Massachusetts.
- Beltsville, Maryland.
- Berea, Kentucky, in cooperation with Berea College.
- Burlington, Vermont, in cooperation with the University of Vermont.
- Delaware, Ohio.
- Durham, New Hampshire, in cooperation with the University of New Hampshire.
- Hamden, Connecticut, in cooperation with Yale University.
- Kingston, Pennsylvania.
- Morgantown, West Virginia, in cooperation with West Virginia University, Morgantown.
- Orono, Maine, in cooperation with the University of Maine, Orono.
- Parsons, West Virginia.
- Pennington, New Jersey.
- Princeton, West Virginia.
- Syracuse, New York, in cooperation with the State University of New York College of Environmental Sciences and Forestry at Syracuse University, Syracuse.
- Warren, Pennsylvania.